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(54) AIRCRAFT SYSTEM OPERATIONAL TESTING

BETRIEBSPRÜFUNG EINES FLUGZEUGSYSTEMS

ESSAIS DE FONCTIONNEMENT DE SYSTÈME D'AÉRONEF

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(73) Proprietor: **The Boeing Company**
Arlington, VA 22202 (US)

(72) Inventors:
- **AARON, Noah Eric**
  Chicago, 60606-2016 (US)
- **PREWETT, Emily M.**
  Chicago, 60606-2016 (US)

(74) Representative: **Plasseraud IP**
66, rue de la Chaussée d'Antin
75440 Paris Cedex 09 (FR)

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Description

FIELD OF THE DISCLOSURE

[0001] The present disclosure is generally related to operational testing of aircraft systems.

BACKGROUND

[0002] Operational tests for aircraft systems are generally targeted to individual aircraft systems. As a result, a large number of tests have to be performed for the many aircraft systems included in a typical aircraft. Performing a large number of tests can be costly and time consuming. In addition, if a change is expected to have an effect on a particular system, the operational tests for that particular system are performed and unexpected effects of the change on other aircraft systems can go undetected. U.S. Patent Application Publication No. 2016/246304 A1 discusses near-flight testing maneuvers for an autonomous aircraft. The document entitled "European Union Aviation Safety Agency Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft," downloadable at www.easa.europa.eu/downloads/100577/en describes certification specifications and means of convergence for large rotorcraft.

SUMMARY

[0003] In a particular implementation, a method of testing is provided as set forth in the appended claims.

[0004] In another particular implementation, an aircraft is provided as set forth in the appended claims.

[0005] In yet another particular implementation, a computer-readable storage device is provided as set forth in the appended claims.

[0006] In the following, embodiments and/or examples not falling within the scope of the claims should be understood as mere examples useful for understanding the present invention.

[0007] The features, functions, and advantages described herein can be achieved independently in various implementations or may be combined in yet other implementations, further details of which can be found with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a diagram that illustrates a system configured to perform operational testing of aircraft systems.

FIG. 2 is a diagram of an example of an analyzer of FIG. 1.

FIG. 3 is a flow chart of an example of a method of operational testing of aircraft systems.

FIG. 4 is a flow chart illustrating a life cycle of an aircraft that is configured to perform operational testing of aircraft systems.

FIG. 5 is a block diagram of an aircraft that is configured to perform operational testing of aircraft systems.

FIG. 6 is a block diagram of a computing environment including a computing device configured to support aspects of computer-implemented methods and computer-executable program instructions (or code) according to the present disclosure.

DETAILED DESCRIPTION

[0009] Aspects disclosed herein present operational testing of aircraft systems. For example, an aircraft includes one or more sensors that monitor aircraft conditions. An analyzer has access to test matrices for aircraft systems of the aircraft. For example, a first test matrix of a first aircraft system indicates a set of operational tests for the first aircraft system. As an illustrative example, the first aircraft system includes a fuel system of the aircraft and the first operational test is for determining the effects of changes in altitude on fuel consumption. During performance of a first operational test of the first test matrix, sensor data from the sensors is collected. For example, the sensor data includes first sensor data (e.g., detected altitude measurements) specified by the first operational test. The sensor data also includes other sensor data not specified by the first test matrix. As an illustrative example, the sensor data includes detected engine temperature measurements.

[0010] The analyzer evaluates the first operational test by processing the first sensor data (e.g., detected altitude) using a first analytic model of the first aircraft system (e.g., the fuel system). For example, the analyzer generates first predicted sensor data (e.g., predicted fuel consumption) by using the first analytic model to process the first sensor data (e.g., detected altitude). The analyzer generates a first error measure by comparing a first subset of the sensor data (e.g., detected fuel consumption) and the first predicted sensor data (e.g., the predicted fuel consumption).

[0011] Additionally, analytic models of other aircraft systems are used to process sensor data generated during the first operational test. For example, the analyzer evaluates a second operational test (e.g., mapping airspeed to engine temperature) of the second test matrix by using a second analytic model of a second aircraft system (e.g., an engine). To illustrate, the analyzer generates second predicted sensor data (e.g., predicted engine temperature) by using the second analytic model to process the second sensor data (e.g., detected engine temperature).

[0012] The analyzer generates a second error measure by comparing a second subset of the sensor data (e.g., detected engine temperature) and the second predicted sensor data (e.g., the predicted engine temperature). A portion of the second test matrix can thus be covered during performance of the first operational test of the first test matrix without having to separately perform the second operational test. In a particular example, the first operational test could be scheduled subsequent to a change in the aircraft that is expected to have an effect on the first aircraft system and not expected to have any effect on the second aircraft system. The analyzer can evaluate the second operational test using the sensor data generated during the first aircraft system and could discover unexpected effects on the second aircraft system of the change to the aircraft.

[0013] The figures and the following description illustrate specific exemplary embodiments.

[0014] Furthermore, any examples described herein are intended to aid in understanding the principles of the disclosure and are to be construed as being without limitation. As a result, this disclosure is not limited to the specific embodiments or examples described below, but by the claims only.

[0015] As used herein, various terminology is used for the purpose of describing particular implementations only and is not intended to be limiting. For example, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. Further, some features described herein are singular in some implementations and plural in other implementations. To illustrate, FIG. 1 depicts a system 100 including one or more processors 128 ("processor(s)" in FIG. 1), which indicates that in some implementations the system 100 includes a single processor 128 and in other implementations the system 100 includes multiple processors 128. For ease of reference herein, such features are generally introduced as "one or more" features and are subsequently referred to in the singular unless aspects related to multiple of the features are being described.

[0016] The terms "comprise," "comprises," and "comprising" are used interchangeably with "include," "includes," or "including." Additionally, the term "wherein" is used interchangeably with the term "where." As used herein, "exemplary" indicates an example, an implementation, and/or an aspect, and should not be construed as limiting or as indicating a preference or a preferred implementation. As used herein, an ordinal term (e.g., "first," "second," "third," etc.) used to modify an element, such as a structure, a component, an operation, etc., does not by itself indicate any priority or order of the element with respect to another element, but rather merely distinguishes the element from another element having a same name (but for use of the ordinal term). As used herein, the term "set" refers to a grouping of one or more elements, and the term "plurality" refers to multiple elements.

[0017] As used herein, "generating," "calculating," "using," "selecting," "accessing," and "determining" are interchangeable unless context indicates otherwise. For example, "generating," "calculating," or "determining" a parameter (or a signal) can refer to actively generating, calculating, or determining the parameter (or the signal) or can refer to using, selecting, or accessing the parameter (or signal) that is already generated, such as by another component or device. As used herein, "coupled" can include "communicatively coupled," "electrically coupled," or "physically coupled," and can also (or alternatively) include any combinations thereof. Two devices (or components) can be coupled (e.g., communicatively coupled, electrically coupled, or physically coupled) directly or indirectly via one or more other devices, components, wires, buses, networks (e.g., a wired network, a wireless network, or a combination thereof), etc. Two devices (or components) that are electrically coupled can be included in the same device or in different devices and can be connected via electronics, one or more connectors, or inductive coupling, as illustrative, non-limiting examples. In some implementations, two devices (or components) that are communicatively coupled, such as in electrical communication, can send and receive electrical signals (digital signals or analog signals) directly or indirectly, such as via one or more wires, buses, networks, etc. As used herein, "directly coupled" is used to describe two devices that are coupled (e.g., communicatively coupled, electrically coupled, or physically coupled) without intervening components.

[0018] Referring to FIG. 1, a system configured to perform operational testing of aircraft systems is shown and generally designated system 100. The system 100 includes a device 102 that includes a memory 132 coupled to one or more processors 128. In a particular aspect, the device 102 includes one or more interfaces 134 that are configured to receive sensor data 151. In a particular aspect, the interface 134 (e.g., a communication interface) includes at least one of a wired interface or a wireless interface. The memory 132 includes a computer-readable medium (e.g., a computer-readable storage device) that stores instructions 116 that are executable by the processor 128. The instructions 116 are executable to initiate, perform, or control operations to aid in performing operational testing of aircraft systems 154.

[0019] In a particular example, the memory 132 is configured to store analytic models 111 of the aircraft systems 154. In a particular example, the analytic models 111 include at least one of a physics model, an empirical model, a statistical model, a simulation model, or a combination thereof. In various examples, the analytic models 111 include an engine model, a fuel system model, a nose wheel steering system model, a stabilizer system model, an air-conditioning system model, a communication system model, a propulsion system model, an electrical system model, an environmental system model, a hydraulic system model, or a combination thereof. To illustrate, the analytic models 111 include a first analytic model 103 of a first aircraft system 156 (e.g., a fuel system), a second analytic model 113 of a second aircraft system 158 (e.g., an engine), one or more additional analytic models of one or more additional aircraft systems, or a combination thereof.

[0020] The analytic models 111 are configured to predict aircraft system responses based on sensor data 151. For example, the first analytic model 103 is configured to predict responses of the first aircraft system 156 (e.g., the fuel system) to at least a portion of the sensor data 151, the second analytic model 113 is configured to predict responses of the second aircraft system 158 (e.g., the engine) to at least a portion of the sensor data 151, and one or more additional analytic models are configured to predict responses of one or more additional aircraft systems to at least some of the sensor data 151. The sensor data 151 is generated by one or more sensors 152 that are configured to monitor the aircraft systems 154 of an aircraft 104. In a particular aspect, the sensors 152 include one or more on-board sensors, one or more flight-test sensors, or a combination thereof. In a particular aspect, one or more of the sensors 152 are at least one of coupled to, proximate to, internal to, external to, integrated into, or separate from the aircraft 104.

[0021] In a particular aspect, the memory 132 is configured to store test matrices 131 for the aircraft systems 154. The test matrices 131 include a first test matrix 133 for the first aircraft system 156 (e.g., the fuel system), a second test matrix 173 for the second aircraft system 158 (e.g., the engine) and, optionally, one or more additional test matrices for one or more additional aircraft systems. The first test matrix 133 describes one or more first operational tests 121. For example, the first operational tests 121 include a first operational test 123. In a particular example, the first operational test 123 includes testing changes in fuel consumption of the first aircraft system 156 (e.g., the fuel system) responsive to changes in altitude. The second test matrix 173 describes one or more second operational tests 161. For example, the second operational tests 161 include a second operational test 163. In a particular example, the second operational test 163 includes testing changes in engine temperature of the second aircraft system 158 (e.g., the engine) response to changes in airspeed. In some implementations, one or more additional test matrices describe one or more additional operational tests for one or more additional aircraft systems.

[0022] The processor 128 includes an analyzer 130 that can be implemented at least in part by the processor 128 executing the instructions 116. The processor 128 can be implemented as a single processor or as multiple processors, such as in a multi-core configuration, a multiprocessor configuration, a distributed computing configuration, a cloud computing configuration, or any combination thereof. In some implementations, one or more portions of the analyzer 130 are implemented by the processor 128 using dedicated hardware, firmware, or a combination thereof.

[0023] The analyzer 130 includes an evaluator 135 coupled via an error analyzer 136 to an output generator 138. The output generator 138 is coupled to a display device 120. Although, the device 102, the aircraft 104, and the display device 120 are illustrated as separate, in some implementations two or more components of the device 102, the aircraft 104, or the display device 120 are combined. For example, in a particular implementation, the display device 120, one or more components of the device 102, or a combination thereof, are integrated into or onboard the aircraft 104. The evaluator 135 is configured to evaluate an operational test by processing sensor data using an analytic model. For example, the evaluator 135 generates predicted sensor data based on the evaluation. The error analyzer 136 is configured to generate an error measure based on a comparison of predicted sensor data and a subset of sensor data. The output generator 138 is configured to generate an aircraft test output based on the error measure.

[0024] During operation, the analyzer 130 obtains the test matrices 131. For example, the analyzer 130 obtains the test matrices 131 from a test server during a pre-flight sequence. The aircraft 104 performs the first operational test 123. In a particular implementation, the analyzer 130 sends an instruction to the aircraft 104 to initiate the first operational test 123 (e.g., fly at various altitudes during a particular time period or during a flight). In an alternative implementation, a pilot initiates the first operational test 123. In a particular aspect, the first operational test 123 includes at least one of a ground test, a taxi test, or a flight test that is to be performed while the aircraft 104 is on the ground (e.g., parked), while the aircraft 104 is taxiing, or during flight, respectively.

[0025] The sensors 152 generate sensor data 151 during the first operational test 123. For example, the sensors 152 include a first sensor, a second sensor, a third sensor, and a fourth sensor that monitor changes in altitude, changes in fuel consumption, changes in airspeed, and changes in engine temperature, respectively. To illustrate, the sensor data 151 includes sensor data 175 (e.g., altitude measurements), sensor data 147 (e.g., fuel consumption measurements), sensor data 153 (e.g., airspeed measurements), sensor data 157 (e.g., engine temperature measurements), or a combination thereof. Although the sensor data 175, the sensor data 147, the sensor data 153, and the sensor data 157 are illustrated in FIG. 1 as distinct subsets of the sensor data 151, in some examples, one or more of the sensor data 175, the sensor data 147, the sensor data 153, or the sensor data 157 may overlap.

[0026] The analyzer 130 obtains the sensor data 151 from the sensors 152. The sensor data 151 includes the sensor data 175 (e.g., altitude measurements) in a first range 145 (e.g., between a first altitude and a second altitude) specified by the first test matrix 133. The sensor data 151 includes the sensor data 153 (e.g., airspeed measurements) that is not specified by the first test matrix

133.

[0027] The analyzer 130 evaluates one or more operational tests by processing the sensor data 151 based on the analytic models 111. For example, the evaluator 135, in response to determining that the sensor data 151 is generated during the first operational test 123, evaluates the first operational test 123 by using the first analytic model 103 to process the sensor data 175 (e.g., altitude measurements), as further described with reference to FIG. 2. To illustrate, the evaluator 135 generates first predicted sensor data 141 based on the evaluation of the first operational test 123. In a particular example, the evaluator 135, in response to determining that the first operational test 123 tests for responsiveness of the first aircraft system 156 (e.g., the fuel system) to changes in altitude, provides the sensor data 175 (e.g., altitude measurements) as input to the first analytic model 103, and the first analytic model 103 determines a predicted response of the first aircraft system 156 to the sensor data 175. To illustrate, the predicted response indicates predicted sensor data for various sensors. In a particular aspect, the evaluator 135, in response to determining that the first operational test 123 tests for changes in fuel consumption of the first aircraft system 156 (e.g., the fuel system), extracts the first predicted sensor data 141 (e.g., predicted fuel consumption) from the predicted response.

[0028] The error analyzer 136 generates a first error measure 143 based on a comparison of the first predicted sensor data 141 (e.g., the predicted fuel consumption) and the sensor data 147 (e.g., the detected fuel consumption), as further described with reference to FIG. 2. The output generator 138 determines a first test coverage metric 139 based at least in part on a first range 145 of the sensor data 175 (e.g., the detected altitude), as further described with reference to FIG. 2. For example, the first test coverage metric 139 indicates how much of the first test matrix 133 has been covered. In a particular aspect, the output generator 138 determines a first test convergence metric 177 based on the first error measure 143, as further described with reference to FIG. 2. The first test convergence metric 177 indicates whether the results of evaluating the first operational tests 121 of the first test matrix 133 have converged. The output generator 138 generates a first aircraft test output 149 indicating the first error measure 143, the first test coverage metric 139, the first test convergence metric 177, or a combination thereof.

[0029] In a particular aspect, the output generator 138, in response to determining that the first error measure 143 fails to satisfy an error criterion, generates the first aircraft test output 149 indicating that an error is detected in the first analytic model 103, the first aircraft system 156, or both. In a particular aspect, the output generator 138, in response to determining that the first test coverage metric 139 satisfies a coverage criterion (e.g., at least 90% coverage), that the first test convergence metric 177 satisfies a convergence criterion (e.g., standard deviation converged within a threshold range with a 95% confidence), or both, generates the first aircraft test output 149 indicating that testing of the first analytic model 103 is complete, designates the first analytic model 103 as satisfying testing completion criteria, or both.

[0030] The analyzer 130 uses the sensor data 151 generated during the first operational test 123 to evaluate one or more additional operational tests. For example, the evaluator 135, in response to determining that the second analytic model 113 is not designated as satisfying testing completion criteria, evaluates the second operational test 163 by using the second analytic model 113 to process the sensor data 153 (e.g., airspeed measurements) generated during the first operational test 123, as further described with reference to FIG. 2. To illustrate, the evaluator 135 generates second predicted sensor data 181 based on the evaluation of the second operational test 163. In a particular example, the evaluator 135, in response to determining that the second operational test 163 tests for responsiveness of the second aircraft system 158 (e.g., the engine) to changes in airspeed, provides the sensor data 153 (e.g., airspeed measurements) as input to the second analytic model 113, and the second analytic model 113 determines a predicted response of the second aircraft system 158 to the sensor data 153. To illustrate, the predicted response indicates predicted sensor data for various sensors. In a particular aspect, the evaluator 135, in response to determining that the second operational test 163 tests for changes in engine temperature of the second aircraft system 158 (e.g., the engine), extracts the second predicted sensor data 181 (e.g., predicted engine temperature) from the predicted response.

[0031] The error analyzer 136 generates a second error measure 183 based on a comparison of the second predicted sensor data 181 (e.g., the predicted engine temperature) and the sensor data 157 (e.g., the detected engine temperature), as further described with reference to FIG. 2. The output generator 138 determines a second test coverage metric 197 based at least in part on a second range 195 of the sensor data 153 (e.g., the detected engine temperature), as further described with reference to FIG. 2. The second test coverage metric 197 indicates how much of the second test matrix 173 has been covered. In a particular aspect, the output generator 138 determines a second test convergence metric 179 based on the second error measure 183, as further described with reference to FIG. 2. The second test convergence metric 179 indicates whether the results of the evaluations of the second operational tests 161 of the second test matrix 173 have converged. The output generator 138 generates a second aircraft test output 199 indicating the second error measure 183, the second test coverage metric 197, the second test convergence metric 179, or a combination thereof.

[0032] In a particular aspect, the output generator 138, in response to determining that the second error measure 183 fails to satisfy an error criterion, generates the second aircraft test output 199 indicating that an error is detected in the second analytic model 113, the second aircraft system 158, or both. In a particular aspect, the output generator 138, in response to determining that the second test coverage metric 197 satisfies a coverage criterion (e.g., at least 90% coverage), that the second test convergence metric 179 satisfies a convergence criterion (e.g., standard deviation converged within a threshold range with a 95% confidence), or both, generates the second aircraft test output 199 indicating that testing of the second analytic model 113 is complete, designates the second analytic model 113 as satisfying testing completion criteria, or both. Similarly, the analyzer 130 can use the sensor data 151 generated during the first operational test 123 to evaluate one or more additional operational tests. In a particular implementation, over time as more analytic models are designated as satisfying testing completion criteria, fewer operational tests are evaluated.

[0033] In some implementations, the analyzer 130, in response to determining that an aircraft system has been updated, resets the coverage metric and the convergence metric for an analytic model for one or more of the aircraft systems 154. For example, the analyzer 130, in response to determining that the second aircraft system 158 has been updated at a first time, resets the second test coverage metric 197 to a default value (e.g., indicating no coverage), the second test convergence metric 179 to a default value (e.g., indicating no convergence), or both. In a particular implementation, the analyzer 130, in response to determining that the second aircraft system 158 has been updated at the first time, resets the first test coverage metric 139 to a default value (e.g., indicating no coverage), the first test convergence metric 177 to a default value (e.g., indicating no convergence), or both. Operational testing of analytic models can thus be restarted subsequent to an update.

[0034] The output generator 138 provides the first aircraft test output 149, the second aircraft test output 199, or both, to the display device 120. In a particular example, a user 118 can submit the first analytic model 103 or the second analytic model 113 that has satisfied testing completion criteria for certification.

[0035] The system 100 thus enables automatic evaluation of one or more operational tests (e.g., the second operational test 163) based on the sensor data 151 generated during performance of another operational test (e.g., the first operational test 123). For example, the sensor data 151 generated during the first operational test 123 can be automatically used to evaluate multiple operational tests that have not satisfied testing completion criteria. In a particular example, the first operational test 123 is performed subsequent to a change to the aircraft 104 that is not expected to have an effect on the second aircraft system 158. Automatically evaluating the second operational test 163 can help identify any unexpected effects on the second aircraft system 158. For example, the output generator 138 can generate the second aircraft test output 199 indicating an error in the second analytic model 113, the second aircraft system 158, or both, in response to determining that the second error measure 183 fails to satisfy an error criterion.

[0036] Although the evaluator 135, the error analyzer 136, and the output generator 138 are depicted as separate components, in other implementations the described functionality of two or more of the evaluator 135, the error analyzer 136, and the output generator 138 can be performed by a single component. In some implementations, one or more components of each of the evaluator 135, the error analyzer 136, the output generator 138, the analyzer 130, the processor 128, the device 102, the aircraft 104, or the display device 120 can be represented in hardware, such as via an application-specific integrated circuit (ASIC) or a field-programmable gate array (FPGA), or the operations described with reference to the elements may be performed by a processor executing computer-readable instructions.

[0037] Referring to FIG. 2, an example of the analyzer 130 is shown. In a first example, an operational test 223, an analytic model 213, sensor data 253, predicted sensor data 241, a sensor data 257, an error measure 243, a range 245, a test matrix 225, a test coverage metric 247, a test convergence metric 249, and an aircraft test output 251 correspond to the first operational test 123, the first analytic model 103, the sensor data 175, the first predicted sensor data 141, the sensor data 147, the first error measure 143, the first range 145, the first test matrix 133, the first test coverage metric 139, the first test convergence metric 177, and the first aircraft test output 149 of FIG. 1, respectively. In a second example, the operational test 223, the analytic model 213, the sensor data 253, the predicted sensor data 241, the sensor data 257, the error measure 243, the range 245, the test matrix 225, the test coverage metric 247, the test convergence metric 249, and the aircraft test output 251 correspond to the second operational test 163, the second analytic model 113, the sensor data 153, the second predicted sensor data 181, the sensor data 157, the second error measure 183, the second range 195, the second test matrix 173, the second test coverage metric 197, the second test convergence metric 179, and the second aircraft test output 199 of FIG. 1, respectively.

[0038] During operation, the evaluator 135 evaluates the operational test 223 of the test matrix 225 by using the analytic model 213 to process the sensor data 253. The evaluator 135 generates the predicted sensor data 241 based on the evaluation. For example, the evaluator 135, in response to determining that the operational test 223 for a particular aircraft system of the aircraft systems 154 tests for changes in a second type of sensor data responsive to changes in a first type of sensor data, uses the analytic model 213 for the particular aircraft system to process the sensor data 253 of the first type to generate the predicted sensor data 241 of the second type.

[0039] The error analyzer 136 generates an error measure 243 based on a comparison of the sensor data

257 (e.g., detected sensor data of the second type) with the predicted sensor data 241. In a particular example, the error measure 243 indicates a difference, a ratio, or both, of the sensor data 257 and the predicted sensor data 241.

[0040] The output generator 138 determines the range 245 of (e.g., a minimum value and a maximum value indicated by) the sensor data 253 that is generated by a first sensor of the sensors 152. The output generator 138 determines, based on the range 245, the test coverage metric 247 for the test matrix 225. For example, the test matrix 225 indicates a first range 261 (e.g., a first altitude to a second altitude or a first airspeed to a second airspeed) of data of the first sensor that is indicated by the test matrix 225. To illustrate, the test matrix 225 indicates that responses of the particular aircraft system are to be tested for the first range 145 of data of the first sensor. The output generator 138 updates the test coverage metric 247 to indicate that the range 245 of data of the first sensor has been tested.

[0041] In a particular aspect, the analyzer 130 receives sets of sensor data during a data collection period. In a particular example, the data collection period is initiated in response to a most recent update of the particular aircraft system, a most recent update of any of the aircraft systems 154, a most recent update of another particular aircraft system of the aircraft systems 154, or a combination thereof. In a particular aspect, the data collection period is initiated in response to receiving a user input.

[0042] In a particular aspect, the analyzer 130 updates the test coverage metric 247 during the data collection period based on the sets of sensor data. For example, the analyzer 130 determines the range 245 of the sensor data 253 that is generated by the first sensor during a first time period of the data collection period and determines a second range 263 of sensor data generated by the first sensor during a second time period of the data collection period. In a particular aspect, the first time period is during performance of the operational test 223 and the second time period is during performance of another operational test of the test matrix 225. The analyzer 130 updates the test coverage metric 247 to indicate that the range 245 and the second range 263 has been tested out of the first range 261 indicated by the test matrix 225. In a particular aspect, the output generator 138 updates the test coverage metric 247 to indicate a proportion (e.g., a percentage) of the first range 261 that has been tested during the data collection period.

[0043] In a particular aspect, the output generator 138 determines a test convergence metric 249 based on the sets of sensor data received during the data collection period. For example, the output generator 138 determines the test convergence metric 249 to indicate whether error measures corresponding to the sets of sensor data are converging. To illustrate, the error analyzer 136 determines the error measure 243 corresponding to the sensor data 253 that is generated by the first sensor during the first time period and determines a second error measure corresponding to the sensor data generated by the first sensor during the second time period.

[0044] The output generator 138 determines the test convergence metric 249 by using statistical methods to process the error measure 243, the second error measure, one or more additional error measures corresponding to one or more additional sets of sensor data, or a combination thereof. For example, the output generator 138 updates the test convergence metric 249 to indicate a standard deviation calculated based on the error measure 243, the second error measure, the additional error measures, or a combination thereof. In a particular aspect, the output generator 138 updates the test convergence metric 249 to indicate a confidence interval associated with the standard deviation.

[0045] The output generator 138 generates the aircraft test output 251 based on the error measure 243, the test coverage metric 247, the test convergence metric 249, or a combination thereof. In a particular aspect, the output generator 138, in response to determining that the error measure 243 fails to satisfy (e.g., is greater than or equal to) an error criterion (e.g., an error threshold), generates the aircraft test output 251 to indicate that an error is detected in the analytic model 213, the particular aircraft system, or both.

[0046] In a particular aspect, the output generator 138, in response to determining that the test coverage metric 247 satisfies a coverage criterion, that the test convergence metric 249 satisfies a convergence metric, or both, generates the aircraft test output 251 indicating that testing of the analytic model 213 is complete.

[0047] In a particular example, the analyzer 130 evaluates the operational test 223 of the test matrix 225 based on the sensor data 253 that is generated during performing the operational test 223 or during performance of another operational test of the test matrix 225. In an alternative example, the analyzer 130 evaluates the operational test 223 of the test matrix 225 without performing an operational test of the test matrix 225. In this example, the analyzer 130 evaluates the operational test 223 based on the sensor data 253 that is generated during performance of another operational test of another test matrix. The analyzer 130 thus enables covering at least part of the test matrix 225 based on sensor data generated during performance of an operational test that is not included in the test matrix 225.

[0048] Referring to FIG. 3, an example of a method of operational testing of aircraft systems is shown and generally designated method 300. In a particular aspect, one or more operations of the method 300 are performed by the evaluator 135, the error analyzer 136, the output generator 138, the analyzer 130, the processor 128, the device 102, the aircraft 104, the system 100 of FIG. 1, or a combination thereof.

[0049] The method 300 includes obtaining a first test matrix for a first aircraft system and a second test matrix for a second aircraft system, at 302. For example, the analyzer 130 of FIG. 1 obtains the first test matrix 133 for the first aircraft system 156 and the second test matrix 173 for the second aircraft system 158.

[0050] The method 300 also includes, during a first operational test of the first test matrix, obtaining sensor data that includes first sensor data in a range specified by the first test matrix and second sensor data that is not specified by the first test matrix, at 304. For example, the evaluator 135 of FIG. 1, during a first operational test 123 of the first test matrix 133, obtains the sensor data 151 that includes the sensor data 175 (e.g., detected altitude) in the first range 145 (e.g., within the first range 261) specified by the first test matrix 133 and that also includes the sensor data 153 (e.g., detected airspeed) that is not specified by the first test matrix 133, as described with reference to FIGS. 1-2.

[0051] The method 300 further includes evaluating the first operational test by processing the first sensor data using a first analytic model of the first aircraft system, at 306. For example, the evaluator 135 of FIG. 1 evaluates the first operational test 123 by processing the sensor data 175 using the first analytic model 103 of the first aircraft system 156, as described with reference to FIGS. 1-2.

[0052] The method 300 also includes generating first predicted sensor data based on the evaluation of the first operational test, at 308. For example, the evaluator 135 of FIG. 1 generates the first predicted sensor data 141 based on the evaluation of the first operational test 123, as described with reference to FIGS. 1-2.

[0053] The method 300 further includes evaluating a second operational test of the second test matrix by processing the second sensor data using a second analytic model of the second aircraft system, at 310. For example, the evaluator 135 of FIG. 1 evaluates the second operational test 163 of the second test matrix 173 by processing the sensor data 153 using the second analytic model 113 of the second aircraft system 158, as described with reference to FIGS. 1-2.

[0054] The method 300 also includes generating second predicted sensor data based on the evaluation of the second operational test, at 312. For example, the evaluator 135 of FIG. 1 generates the second predicted sensor data 181 based on the evaluation of the second operational test 163, as described with reference to FIGS. 1-2.

[0055] The method 300 further includes generating a first error measure by comparing a first subset of the sensor data to the first predicted sensor data, at 314. For example, the error analyzer 136 of FIG. 1 generates the first error measure 143 by comparing the sensor data 147 to the first predicted sensor data 141, as described with reference to FIGS. 1-2.

[0056] The method 300 also includes generating a second error measure by comparing a second subset of the sensor data to the second predicted sensor data, at 316. For example, the evaluator 135 of FIG. 1 generates the second error measure 183 by comparing the sensor data 157 to the second predicted sensor data 181, as described with reference to FIGS. 1-2.

[0057] The method 300 further includes determining, based at least in part on a range of the second sensor data, a test coverage metric of the second test matrix, at 318. For example, the output generator 138 of FIG. 1 determines, based at least in part on the second range 195 of the sensor data 153, the second test coverage metric 197 of the second test matrix 173, as described with reference to FIGS. 1-2.

[0058] The method 300 also includes providing an output to a display device, the output indicating the first error measure, the second error measure, and the test coverage metric, at 320. For example, the output generator 138 of FIG. 1 provides the first aircraft test output 149, the second aircraft test output 199, or both, to the display device 120. The first aircraft test output 149, the second aircraft test output 199, or both, as described with reference to FIGS. 1-2.

[0059] The method 300 thus enables automatic evaluation of the second operational test 163 based on the sensor data 151 generated during performance of the first operational test 123. In a particular example, the sensor data 151 generated during the first operational test 123 can be automatically used to evaluate multiple operational tests of multiple matrices using analytic models of multiple aircraft systems.

[0060] Referring to FIG. 4, a flowchart illustrative of a life cycle of an aircraft that includes the analyzer 130 is shown and designated method 400. During pre-production, the exemplary method 400 includes, at 402, specification and design of an aircraft, such as the aircraft 500 described with reference to FIG. 5. During specification and design of the aircraft, the method 400 may include specification and design of the analyzer 130. At 404, the method 400 includes material procurement, which may include procuring materials for the analyzer 130.

[0061] During production, the method 400 includes, at 406, component and subassembly manufacturing and, at 408, system integration of the aircraft. For example, the method 400 may include component and subassembly manufacturing of the analyzer 130 and system integration of the analyzer 130. At 410, the method 400 includes certification and delivery of the aircraft and, at 412, placing the aircraft in service. In a particular aspect, certification and delivery may include operational testing of the aircraft. Certification and delivery may include certification of the analyzer 130 to place the analyzer 130 in service. While in service by a customer, the aircraft may be scheduled for routine maintenance and service (which may also include modification, reconfiguration, refurbishment, operational testing, and so on). At 414, the method 400 includes performing maintenance and service on the aircraft, which may include performing maintenance and service on the analyzer 130. In a particular aspect, maintenance and service of the aircraft may include operational testing.

[0062] Each of the processes of the method 400 may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

[0063] Aspects of the disclosure can be described in the context of an example of a vehicle. A particular example of a vehicle is an aircraft 500 as shown in FIG. 5.

[0064] In the example of FIG. 5, the aircraft 500 includes an airframe 518 with the aircraft systems 154, the sensors 152, and an interior 522. Examples of the aircraft systems 154 include one or more of a propulsion system 524, an electrical system 526, an environmental system 528, a hydraulic system 530, and the analyzer 130. Any number of other systems may be included. In a particular aspect, the aircraft 500 corresponds to the aircraft 104 of FIG. 1.

[0065] FIG. 6 is a block diagram of a computing environment 600 including a computing device 610 configured to support aspects of computer-implemented methods and computer-executable program instructions (or code) according to the present disclosure. For example, the computing device 610, or portions thereof, is configured to execute instructions to initiate, perform, or control one or more operations described with reference to FIGS. 1-6.

[0066] The computing device 610 includes one or more processors 620. In a particular aspect, the processor(s) 620 correspond to the processor 128 of FIG. 1. The processor(s) 620 are configured to communicate with system memory 630, one or more storage devices 640, one or more input/output interfaces 650, one or more communications interfaces 660, or any combination thereof. The system memory 630 includes volatile memory devices (e.g., random access memory (RAM) devices), nonvolatile memory devices (e.g., read-only memory (ROM) devices, programmable read-only memory, and flash memory), or both. The system memory 630 stores an operating system 632, which may include a basic input/output system for booting the computing device 610 as well as a full operating system to enable the computing device 610 to interact with users, other programs, and other devices. The system memory 630 stores system (program) data 636, such as the analytic models 111, the test matrices 131, the sensor data 151, the first predicted sensor data 141, the second predicted sensor data 181, the first error measure 143, the second error measure 183, the first range 145, the second range 195, the first test coverage metric 139, the second test coverage metric 197, the first test convergence metric 177, the second test convergence metric 179, the first aircraft test output 149, the second aircraft test output 199, the display device 120 of FIG. 1, the operational test 223, the sensor data 253, the analytic model 213, the predicted sensor data 241, the sensor data 257, the error measure 243, the test matrix 225, the range 245, the test coverage metric 247, the test convergence metric 249, the aircraft test output 251, the first range 261, the second range 263 of FIG. 2, or a combination thereof.

[0067] The system memory 630 includes one or more applications 634 (e.g., sets of instructions) executable by the processor(s) 620. As an example, the one or more applications 634 include instructions executable by the processor(s) 620 to initiate, control, or perform one or more operations described with reference to FIGS. 1-6. To illustrate, the one or more applications 634 include instructions executable by the processor(s) 620 to initiate, control, or perform one or more operations described with reference to the analyzer 130.

[0068] In a particular implementation, the system memory 630 includes a non-transitory, computer-readable medium (e.g., a computer-readable storage device) storing the instructions that, when executed by the processor(s) 620, cause the processor(s) 620 to initiate, perform, or control operations to perform or analyze operational testing of aircraft systems. In a particular aspect, the instructions cause the processor(s) 620 to obtain a first test matrix for a first aircraft system and a second test matrix for a second aircraft system. The instructions also cause the processor(s) 620 to, during a first operational test of the first test matrix, obtain sensor data that includes first sensor data in a range specified by the first test matrix and second sensor data that is not specified by the first test matrix. The instructions further cause the processor(s) 620 to evaluate the first operational test by processing the first sensor data using a first analytic model of the first aircraft system. The instructions also cause the processor(s) 620 to generate first predicted sensor data based on the evaluation of the first operational test. The instructions further cause the processor(s) 620 to evaluate a second operational test of the second test matrix by processing the second sensor data using a second analytic model of the second aircraft system. The instructions also cause the processor(s) 620 to generate second predicted sensor data based on the evaluation of the second operational test. The instructions further cause the processor(s) 620 to generate a first error measure by comparing a first subset of the sensor data to the first predicted sensor data. The instructions also cause the processor(s) 620 to generate a second error measure by comparing a second subset of the sensor data to the second predicted sensor data. The instructions further cause the processor(s) 620 to determine, based at least in part on a range of the second sensor data, a test coverage metric of the second test matrix. The instructions also cause the processor(s) 620 to provide an output to a display device, the output indicating the first error measure, the second error measure, and the test coverage metric.

[0069] In a particular aspect, each of the first operational test and the second operational test includes at least one of a ground test, a taxi test, or a flight test. In a particular aspect, the instructions cause the processor(s) 620 to determine that the second test matrix indicates a first range of data of a first sensor. The instructions also cause the processor(s) 620 to, in response to determining that a second range of data from the first sensor has been processed using the second analytic model during a data collection period, determine the test coverage metric based at least in part on a third range of data that is included in the first range of data and is not included in the second range of data. The range of the second sensor data includes the second range of data from the first sensor.

[0070] In a particular aspect, the instructions cause the processor(s) 620 to obtain sets of sensor data during a data collection period. The sets of sensor data include the sensor data. The instructions also cause the processor(s) 620 to evaluate a plurality of second operational tests of the second test matrix based on the second analytic model and the sets of sensor data. The plurality of second operational tests includes the second operational test. The instructions further cause the processor(s) 620 to determine a plurality of second error measures based on the evaluation of the plurality of second operational tests. The plurality of second error measures includes the second error measure. The instructions also cause the processor(s) 620 to determine a test convergence metric of the second test matrix based on the plurality of second error measures. In a particular aspect, the instructions cause the processor(s) 620 to, in response to determining that the test coverage metric satisfies a coverage criterion and that a test convergence metric of the second test matrix satisfies a convergence criterion, generate the output to indicate that testing of the second analytic model is complete. In a particular aspect, the instructions cause the processor(s) 620 to, in response to determining that the second error measure fails to satisfy an error criterion, generate the output to indicate that an error is detected in the second analytic model, the second aircraft system, or both.

[0071] The one or more storage devices 640 include nonvolatile storage devices, such as magnetic disks, optical disks, or flash memory devices. In a particular example, the storage devices 640 include both removable and non-removable memory devices. The storage devices 640 are configured to store an operating system, images of operating systems, applications (e.g., one or more of the applications 634), and program data (e.g., the program data 636). In a particular aspect, the system memory 630, the storage devices 640, or both, include tangible computer-readable media. In a particular aspect, one or more of the storage devices 640 are external to the computing device 610. In a particular aspect, the system memory 630 includes the memory 132 of FIG. 1.

[0072] The one or more input/output interfaces 650 that enable the computing device 610 to communicate with one or more input/output devices 670 to facilitate user interaction. For example, the one or more input/output interfaces 650 can include a display interface, an input interface, or both. For example, the input/output interface 650 is adapted to receive input from a user, to receive input from another computing device, or a combination thereof. In some implementations, the input/output interface 650 conforms to one or more standard interface protocols, including serial interfaces (e.g., universal serial bus (USB) interfaces or Institute of Electrical and Electronics Engineers (IEEE) interface standards), parallel interfaces, display adapters, audio adapters, or custom interfaces ("IEEE" is a registered trademark of The Institute of Electrical and Electronics Engineers, Inc. of Piscataway, New Jersey). In some implementations, the input/output device 670 includes one or more user interface devices and displays, including some combination of buttons, keyboards, pointing devices, displays, speakers, microphones, touch screens, and other devices. In a particular aspect, the input/output device 670 includes the display device 120 of FIG. 1.

[0073] The processor(s) 620 are configured to communicate with devices or controllers 680 via the one or more communications interfaces 660. For example, the one or more communications interfaces 660 can include a network interface, such as the interface 134 of FIG. 1. The devices or controllers 680 can include, for example, the aircraft 104 of FIG. 1, one or more other devices, or any combination thereof.

[0074] In some implementations, a non-transitory, computer readable medium stores instructions that, when executed by one or more processors, cause the one or more processors to initiate, perform, or control operations to perform part or all of the functionality described above. For example, the instructions may be executable to implement one or more of the operations or methods of FIGS. 1-6. In some implementations, part or all of one or more of the operations or methods of FIGS. 1-6 may be implemented by one or more processors (e.g., one or more central processing units (CPUs), one or more graphics processing units (GPUs), one or more digital signal processors (DSPs)) executing instructions, by dedicated hardware circuitry, or any combination thereof.

[0075] The illustrations of the examples described herein are intended to provide a general understanding of the structure of the various implementations. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other implementations may be apparent to those of skill in the art upon reviewing the disclosure.

[0076] Accordingly, the disclosure and the figures are to be regarded as illustrative rather than restrictive.

[0077] Combinations of the above implementations, and other implementations not specifically described herein, will be apparent to those of skill in the art upon reviewing the description.

[0078] The Abstract of the Disclosure is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

[0079] As the following claims reflect, the claimed subject matter may be directed to less than all of the features of any of the disclosed examples. Accordingly, the scope of the disclosure is defined by the following claims only.

Claims

1. A method (300) of testing aircraft systems (154) comprising a first aircraft system (156) and a second aircraft system (158), the method (300) comprising:

   obtaining (302), at a device (102, 610), a first test matrix (133, 225) for testing the first aircraft system (156) and a second test matrix (173, 225) for testing the second aircraft system (158), wherein the first test matrix (133, 225) describes a first operational test (123, 223), and the second test matrix (173, 225) describes a second operational test (163, 223);
   during the first operational test (123, 223), obtaining (304), at the device (102, 610), sensor data (151) that comprises first sensor data (175, 253) in a range (145, 245) specified by the first test matrix (133, 225) and second sensor data (153, 253) that is not specified by the first test matrix (133, 225);
   evaluating (306), at the device (102, 610), the first operational test (123, 223) by processing the first sensor data (175, 253) using a first analytic model (103, 213) of the first aircraft system (156), wherein the first analytic model (103, 213) is configured to generate first predicted sensor data (141, 241) based on the first sensor data (175, 253);
   generating (308), at the device (102, 610), the first predicted sensor data (141, 241) based on the evaluation of the first operational test (123, 223);
   evaluating (310), at the device (102, 610), the second operational test (163, 223) by processing the second sensor data (153, 253) using a second analytic model (113, 213) of the second aircraft system (158), wherein the second analytic model (113, 213) is configured to generate second predicted sensor data (181, 241) based on the second sensor data (153, 253);
   generating (312), at the device (102, 610), the second predicted sensor data (181, 241) based on the evaluation of the second operational test (163, 223);
   generating (314), at the device (102, 610), a first error measure (143, 243) by comparing a first subset of the sensor data (147, 257) with the first predicted sensor data (141, 241);
   generating (316), at the device (102, 610), a second error measure (183, 243) by comparing a second subset of the sensor data (157, 257) with the second predicted sensor data (181, 241);
   determining (318), at the device (102, 610), based at least in part on a range (195, 245) of the second sensor data (153, 253), a test coverage metric (197, 247) of the second test matrix (173, 225), wherein the test coverage metric (197, 247) indicates how much of the second test matrix (173, 225) has been covered; and
   providing (320), by the device (102, 610), an output (149, 199, 251) to a display device (120, 670), the output (149, 199, 251) indicating the first error measure (143, 243), the second error measure (183, 243), and the test coverage metric (197, 247).

2. The method (300) of claim 1, wherein the first operational test (123, 223) comprises at least one of a ground test, a taxi test, or a flight test.

3. The method (300) of claim 1 or 2, wherein the first analytic model (103, 213) comprises a physics model, an empirical model, a statistical model, a simulation model, or a combination thereof.

4. The method (300) of claim 1, 2, or 3, further comprising:

   determining that the second test matrix (173, 225) indicates a first range (261) of data of a first sensor (152); and
   in response to determining that a second range (245) of data from the first sensor (152) has been processed using the second analytic model (113, 213) during a data collection period, determining the test coverage metric (197, 247) based at least in part on a third range (263) of data that is included in the first range (261) of data and is not included in the second range (245) of data, wherein the range (195, 245) of the second sensor data (153, 253) includes the second range (195, 245) of data from the first sensor (152).

5. The method (300) of any one of claims 1-4, further comprising determining, based at least in part on the second error measure (183, 243), a test convergence metric (179, 249) of the second test matrix (173, 225), wherein the output (149, 199, 251) indicates the test convergence metric (179, 249).

6. The method (300) of any one of claims 1-5, further comprising:

   receiving sets of sensor data during a data collection period, wherein the sets of sensor data comprise the sensor data (151);
   evaluating a plurality of second operational tests (161) of the second test matrix (173, 225) based

on the second analytic model (113, 213) and the sets of sensor data, wherein the plurality of second operational tests (161) comprises the second operational test (163, 223);

determining a plurality of second error measures based on the evaluations of the plurality of second operational tests (161), wherein the plurality of second error measures comprises the second error measure (183, 243); and

determining a test convergence metric (179, 249) of the second test matrix (173, 225) based on the plurality of second error measures.

7. The method (300) of claim 6, wherein the test convergence metric (179, 249) is based at least in part on a standard deviation of the plurality of second error measures.

8. The method (300) of any one of claims 1-7, further comprising, in response to determining that the test coverage metric (197, 247) satisfies a coverage criterion and that a test convergence metric (179, 249) of the second test matrix (173, 225) satisfies a convergence criterion, generating the output (149, 199, 251) to indicate that testing of the second analytic model (113, 213) is complete.

9. The method (300) of any one of claims 1-8, further comprising, in response to determining that the second error measure (183, 243) fails to satisfy an error criterion, generating the output (149, 199, 251) to indicate that an error is detected in the second analytic model (113, 213), the second aircraft system (158), or both.

10. An aircraft (104, 500) comprising:

aircraft systems (154) comprising a first aircraft system (156) and a second aircraft system (158);

memory (132, 630) configured to store a plurality of analytic models (111) of the aircraft systems (154), the plurality of analytic models (111) comprising a first analytic model (103, 213) of the first aircraft system (156) and a second analytic model (113, 213) of the second aircraft system (158), wherein the first analytic model (103, 213) is configured to generate first predicted sensor data (141, 241) based on first sensor data (175, 253), and the second analytic model (113, 213) is configured to generate second predicted sensor data (181, 241) based on second sensor data (153, 253);

sensors (152) configured to generate sensor data (151) during a first operational test (123, 223) of a first test matrix (133, 225) for testing the first aircraft system (156), wherein the sensor data (151) comprises the first sensor data (175, 253) in a range (145, 245) specified by the first test matrix (133, 225) and the second sensor data (153, 253), wherein the second sensor data (153, 253) is not specified by the first test matrix (133, 225), and wherein the first test matrix (133, 225) describes the first operational test (123, 223);

one or more processors (128, 620) configured to:

evaluate the first operational test (123, 223) by processing the first sensor data (175, 253) using the first analytic model (103, 213);

generate the first predicted sensor data (141, 241) based on the evaluation of the first operational test (123, 223);

evaluate a second operational test (163, 223) of a second test matrix (173, 225) for testing the second aircraft system (158) by processing the second sensor data (153, 253) using the second analytic model (113, 213), wherein the second test matrix (173, 225) describes the second operational test (163, 223);

generate the second predicted sensor data (181, 241) based on the evaluation of the second operational test (163, 223);

generate a first error measure (143, 243) by comparing a first subset of the sensor data (147, 257) with the first predicted sensor data (141, 241);

generate a second error measure (183, 243) by comparing a second subset of the sensor data (157, 257) with the second predicted sensor data (181, 241); and

determine, based at least in part on a range (195, 245) of the second sensor data (153, 253), a test coverage metric (197, 247) of the second test matrix (173, 225) , wherein the test coverage metric (197, 247) indicates how much of the second test matrix (173, 225) has been covered; and

a display device (120, 670) configured to display an output (149, 199, 251) indicating the first error measure (143, 243), the second error measure (183, 243), and the test coverage metric (197, 247).

11. The aircraft (104, 500) of claim 10, wherein the sensors (152) comprise on-board sensors, flight-test sensors, or a combination thereof.

12. The aircraft (104, 500) of claim 10 or 11, wherein the second analytic model (113, 213) comprises a physics model, an empirical model, a statistical model, a simulation model, or a combination thereof.

13. The aircraft (104, 500) of claim 10, 11, or 12, wherein the one or more processors (128, 620) are further configured to, in response to determining that the test coverage metric (197, 247) satisfies a coverage criterion and that a test convergence metric (179, 249) of the second test matrix (173, 225) satisfies a convergence criterion, generate the output (149, 199, 251) to indicate that testing of the second analytic model (113, 213) is complete.

14. The aircraft (104, 500) of any one of claims 10-13, wherein the one or more processors (128, 620) are further configured to, in response to determining that the second error measure (183, 243) fails to satisfy an error criterion, generate the output (149, 199, 251) to indicate that an error is detected in the second analytic model (113, 213), the second aircraft system (158), or both.

15. A computer-readable storage device (132, 630, 640) storing instructions (116, 634) that, when executed by one or more processors (128, 620) of a device, cause the one or more processors (128, 620) to:

obtain a first test matrix (133, 225) for testing a first aircraft system (156) and a second test matrix (173, 225) for testing a second aircraft system (158), wherein the first test matrix (133, 225) describes a first operational test (123, 223), and the second test matrix (173, 225) describes a second operational test (163, 223);
during the first operational test (123, 223), obtain sensor data (151) that comprises first sensor data (175, 253) in a range (145, 245) specified by the first test matrix (133, 225) and second sensor data (153, 253) that is not specified by the first test matrix (133, 225);
evaluate the first operational test (123, 223) by processing the first sensor data (175, 253) using a first analytic model (103, 213) of the first aircraft system (156), wherein the first analytic model (103, 213) is configured to generate first predicted sensor data (141, 241) based on the first sensor data (175, 253);
generate the first predicted sensor data (141, 241) based on the evaluation of the first operational test (123, 223);
evaluate the second operational test (163, 223) by processing the second sensor data (153, 253) using a second analytic model (113, 213) of the second aircraft system (158), wherein the second analytic model (113, 213) is configured to generate second predicted sensor data (181, 241) based on the second sensor data (153, 253);
generate the second predicted sensor data (181, 241) based on the evaluation of the second operational test (163, 223);
generate a first error measure (143, 243) by comparing a first subset of the sensor data (147, 257) with the first predicted sensor data (141, 241);
generate a second error measure (183, 243) by comparing a second subset of the sensor data (157, 257) with the second predicted sensor data (181, 241);
determine, based at least in part on a range (195, 245) of the second sensor data (153, 253), a test coverage metric (197, 247) of the second test matrix (173, 225), wherein the test coverage metric (197, 247) indicates how much of the second test matrix (173, 225) has been covered; and
provide an output (149, 199, 251) to a display device (120, 670), the output (149, 199, 251) indicating the first error measure (143, 243), the second error measure (183, 243), and the test coverage metric (197, 247).

Patentansprüche

1. Verfahren (300) zum Prüfen von Flugzeugsystemen (154), die ein erstes Flugzeugsystem (156) und ein zweites Flugzeugsystem (158) aufweisen, wobei das Verfahren (300) aufweist:

Abrufen (302), an einer Vorrichtung (102, 610), einer ersten Prüfmatrix (133, 225) zum Prüfen des ersten Flugzeugsystems (156) und einer zweiten Prüfmatrix (173, 225) zum Prüfen des zweiten Flugzeugsystems (158), wobei die erste Prüfmatrix (133, 225) eine erste Funktionsprüfung (123, 223) beschreibt und die zweite Prüfmatrix (173, 225) eine zweite Funktionsprüfung (163, 223) beschreibt;
während der ersten Funktionsprüfung (123, 223), Abrufen (304), an der Vorrichtung (102, 610), von Sensordaten (151), die erste Sensordaten (175, 253) in einem von der ersten Prüfmatrix (133, 225) spezifizierten Bereich (145, 245) und von der ersten Prüfmatrix (133, 225) nicht spezifizierte zweite Sensordaten (153, 253) aufweisen;
Evaluieren (306), an der Vorrichtung (102, 610), der ersten Funktionsprüfung (123, 223) durch Verarbeiten der ersten Sensordaten (175, 253) unter Verwendung eines ersten analytischen Modells (103, 213) des ersten Flugzeugsystems (156), wobei das erste analytische Modell (103, 213) konfiguriert ist, um erste vorausgesagte Sensordaten (141, 241) auf Basis der ersten Sensordaten (175, 253) zu erzeugen;
Erzeugen (308), an der Vorrichtung (102, 610), der ersten vorausgesagten Sensordaten (141, 241) auf Basis der Evaluation der ersten Funk-

tionsprüfung (123, 223);
Evaluieren (310), an der Vorrichtung (102, 610), der zweiten Funktionsprüfung (163, 223) durch Verarbeiten der zweiten Sensordaten (153, 253) unter Verwendung eines zweiten analytischen Modells (113, 213) des zweiten Flugzeugsystems (158), wobei das zweite analytische Modell (113, 213) konfiguriert ist, um zweite vorausgesagte Sensordaten (181, 241) auf Basis der zweiten Sensordaten (153, 253) zu erzeugen;
Erzeugen (312), an der Vorrichtung (102, 610), der zweiten vorausgesagten Sensordaten (181, 241) auf Basis der Evaluation der zweiten Funktionsprüfung (163, 223);
Erzeugen (314), an der Vorrichtung (102, 610), eines ersten Fehlermaßes (143, 243) durch Vergleichen eines ersten Subsatzes der Sensordaten (147, 257) mit den ersten vorausgesagten Sensordaten (141, 241);
Erzeugen (316), an der Vorrichtung (102, 610), eines zweiten Fehlermaßes (183, 243) durch Vergleichen eines zweiten Subsatzes der Sensordaten (157, 257) mit den zweiten vorausgesagten Sensordaten (181, 241);
Bestimmen (318), an der Vorrichtung (102, 610), einer Prüfabdeckungsmetrik (197, 247) der zweiten Prüfmatrix (173, 225) mindestens teilweise auf Basis eines Bereichs (195, 245) der zweiten Sensordaten (153, 253), wobei die Prüfabdeckungsmetrik (197, 247) angibt, wieviel der zweiten Prüfmatrix (173, 225) abgedeckt worden ist; und
Liefern (320), von der Vorrichtung (102, 610), einer Ausgabe (149, 199, 251) an eine Anzeigevorrichtung (120, 670), wobei die Ausgabe (149, 199, 251) das erste Fehlermaß (143, 243), das zweite Fehlermaß (183, 243) und die Prüfabdeckungsmetrik (197, 247) angibt.

2. Verfahren (300) nach Anspruch 1, wobei die erste Funktionsprüfung (123, 223) eine Bodenprüfung und/oder eine Rollprüfung und/oder eine Flugprüfung aufweist.

3. Verfahren (300) nach Anspruch 1 oder 2, wobei das erste analytische Modell (103, 213) ein physisches Modell, ein empirisches Modell, ein statistisches Modell, ein Simulationsmodell oder eine Kombination davon aufweist.

4. Verfahren (300) nach Anspruch 1, 2 oder 3, ferner aufweisend:

Bestimmen, dass die zweite Prüfmatrix (173, 225) einen ersten Bereich (261) von Daten eines ersten Sensors (152) angibt; und
als Antwort auf Bestimmen, dass ein zweiter Bereich (245) von Daten aus dem ersten Sensor (152) unter Verwendung des zweiten analytischen Modells (113, 213) während eines Sammlungszeitraums verarbeitet worden ist, Bestimmen der Prüfabdeckungsmetrik (197, 247) auf Basis mindestens teilweise eines dritten Bereichs (263) von Daten, die in dem ersten Datenbereich (261) enthalten sind und in dem zweiten Datenbereich (245) nicht enthalten sind, wobei der Bereich (195, 245) der zweiten Sensordaten (153, 253) den zweiten Bereich (195, 245) von Daten aus dem ersten Sensor (152) enthält.

5. Verfahren (300) nach einem der Ansprüche 1 bis 4, ferner aufweisend Bestimmen einer Prüfkonvergenzmetrik (179, 249) der zweiten Prüfmatrix (173, 225) auf Basis mindestens teilweise des zweiten Fehlermaßes (183, 243), wobei die Ausgabe (149, 199, 251) die Prüfkonvergenzmetrik (179, 249) angibt.

6. Verfahren (300) nach einem der Ansprüche 1 bis 5, ferner aufweisend:

Empfangen von Sensordatensätzen während eines Sammlungszeitraums, wobei die Sensordatensätze die Sensordaten (151) aufweisen;
Evaluieren mehrerer zweiter Funktionsprüfungen (161) der zweiten Prüfmatrix (173, 225) auf Basis des zweiten analytischen Modells (113, 213) und der Sensordatensätze, wobei die mehreren zweiten Funktionsprüfungen (161) die zweite Funktionsprüfung (163, 223) enthalten;
Bestimmen mehrerer zweiter Fehlermaße auf Basis der Evaluationen der mehreren zweiten Funktionsprüfungen (161), wobei die mehreren zweiten Fehlermaße das zweite Fehlermaß (183, 243) enthalten; und
Bestimmen einer Prüfkonvergenzmetrik (179, 249) der zweiten Prüfmatrix (173, 225) auf Basis der mehreren zweiten Fehlermaße.

7. Verfahren (300) nach Anspruch 6, wobei die Prüfkonvergenzmetrik (179, 249) mindestens teilweise auf einer Standardabweichung der mehreren zweiten Fehlermaße basiert.

8. Verfahren (300) nach einem der Ansprüche 1 bis 7, ferner aufweisend als Antwort auf Bestimmen, dass die Prüfabdeckungsmetrik (197, 247) ein Abdeckungskriterium erfüllt und dass eine Prüfkonvergenzmetrik (179, 249) der zweiten Prüfmatrix (173, 225) ein Konvergenzkriterium erfüllt, Erzeugen der Ausgabe (149, 199, 251), um anzugeben, dass Prüfen des zweiten analytischen Modells (113, 213) abgeschlossen ist.

9. Verfahren (300) nach einem der Ansprüche 1 bis 8,

ferner aufweisend als Antwort auf Bestimmen, dass das zweite Fehlermaß (183, 243) ein Fehlerkriterium nicht erfüllt, Erzeugen der Ausgabe (149, 199, 251), um anzugeben, dass ein Fehler in dem zweiten analytischen Modell (113, 213), dem zweiten Flugzeugsystem (158) oder in beiden detektiert worden ist.

10. Flugzeug (104, 500) aufweisend:

Flugzeugsysteme (154), die ein erstes Flugzeugsystem (156) und ein zweites Flugzeugsystem (158) aufweisen;
Speicher (132, 630), die konfiguriert sind, um mehrere analytische Modelle (111) der Flugzeugsysteme (154) zu speichern, wobei die mehreren analytischen Modelle (111) ein erstes analytisches Modell (103, 213) des ersten Flugzeugsystems (156) und ein zweites analytisches Modell (113, 213) des zweiten Flugzeugsystems (158) aufweisen, wobei das erste analytische Modell (103, 213) konfiguriert ist, um erste vorausgesagte Sensordaten (141, 241) auf Basis von ersten Sensordaten (175, 253) zu erzeugen, und das zweite analytische Modell (113, 213) konfiguriert ist, um zweite vorausgesagte Sensordaten (181, 241) auf Basis von zweiten Sensordaten (153, 253) zu erzeugen;
Sensoren (152), die konfiguriert sind, um Sensordaten (151) während einer ersten Funktionsprüfung (123, 223) einer ersten Prüfmatrix (133, 225) zum Prüfen des ersten Flugzeugsystems (156) zu erzeugen, wobei die Sensordaten (151) die ersten Sensordaten (175, 253) in einem von der ersten Prüfmatrix (133, 225) spezifizierten Bereich (145, 245) und die zweiten Sensordaten (153, 253) aufweisen, wobei die zweiten Sensordaten (153, 253) nicht von der ersten Prüfmatrix (133, 225) spezifiziert sind, und wobei die erste Prüfmatrix (133, 225) die erste Funktionsprüfung (123, 223) beschreibt;
einen oder mehrere Prozessoren (128, 620), die konfiguriert sind zum:

Evaluieren der ersten Funktionsprüfung (123, 223) durch Verarbeiten der ersten Sensordaten (175, 253) unter Verwendung des ersten analytischen Modells (103, 213);
Erzeugen der ersten vorausgesagten Sensordaten (141, 241) auf Basis der Evaluation der ersten Funktionsprüfung (123, 223);
Evaluieren einer zweiten Funktionsprüfung (163, 223) einer zweiten Prüfmatrix (173, 225) zum Prüfen des zweiten Flugzeugsystems (158) durch Verarbeiten der zweiten Sensordaten (153, 253) unter Verwendung des zweiten analytischen Modells (113, 213), wobei die zweite Prüfmatrix (173, 225) die zweite Funktionsprüfung (163, 223) beschreibt;
Erzeugen der zweiten vorausgesagten Sensordaten (181, 241) auf Basis der Evaluation der zweiten Funktionsprüfung (163, 223);
Erzeugen eines ersten Fehlermaßes (143, 243) durch Vergleichen eines ersten Subsatzes der Sensordaten (147, 257) mit den ersten vorausgesagten Sensordaten (141, 241);
Erzeugen eines zweiten Fehlermaßes (183, 243) durch Vergleichen eines zweiten Subsatzes der Sensordaten (157, 257) mit den zweiten vorausgesagten Sensordaten (181, 241); und
Bestimmen einer Prüfabdeckungsmetrik (197, 247) der zweiten Prüfmatrix (173, 225) mindestens teilweise auf Basis eines Bereichs (195, 245) der zweiten Sensordaten (153, 253), wobei die Prüfabdeckungsmetrik (197, 247) angibt, wieviel der zweiten Prüfmatrix (173, 225) abgedeckt worden ist; und

eine Anzeigevorrichtung (120, 670), die konfiguriert ist, um eine Ausgabe (149, 199, 251) anzuzeigen, die das erste Fehlermaß (143, 243), das zweite Fehlermaß (183, 243) und die Prüfabdeckungsmetrik (197, 247) angibt.

11. Flugzeug (104, 500) nach Anspruch 10, wobei die Sensoren (152) Bordsensoren, Flugtest-Sensoren oder eine Kombination davon aufweisen.

12. Flugzeug (104, 500) nach Anspruch 10 oder 11, wobei das zweite analytische Modell (113, 213) ein physisches Modell, ein empirisches Modell, ein statistisches Modell, ein Simulationsmodell oder eine Kombination davon aufweist.

13. Flugzeug (104, 500) nach Anspruch 10, 11 oder 12, wobei der eine oder die mehreren Prozessoren (128, 620) ferner konfiguriert sind, um als Antwort auf Bestimmen, dass die Prüfabdeckungsmetrik (197, 257) ein Abdeckungskriterium erfüllt und dass eine Prüfkonvergenzmetrik (179, 249) der zweiten Prüfmatrix (173, 225) ein Konvergenzkriterium erfüllt, die Ausgabe (149, 199, 251) zu erzeugen, um anzugeben, dass Prüfen des zweiten analytischen Modells (113, 213) abgeschlossen ist.

14. Flugzeug (104, 500) nach einem der Ansprüche 10 bis 13, wobei der eine oder die mehreren Prozessoren (128, 620) ferner konfiguriert sind, um als Antwort auf Bestimmen, dass das zweite Fehlermaß (183, 243) ein Fehlerkriterium nicht erfüllt, die Ausgabe (149, 199, 251) zu erzeugen, um anzugeben, dass ein Fehler in dem zweiten analytischen Modell (113, 213), dem zweiten Flugzeugsystem (158) oder in beiden detektiert worden ist.

15. Computerlesbare Speichervorrichtung (132, 630, 640) mit darauf gespeicherten Befehlen (116, 634), die, wenn sie von einem oder mehreren Prozessoren (128, 620) einer Vorrichtung ausgeführt werden, den einen oder die mehreren Prozessoren (128, 620) veranlassen zum:

Abrufen einer ersten Prüfmatrix (133, 225) zum Prüfen eines ersten Flugzeugsystems (156) und einer zweiten Prüfmatrix (173, 225) zum Prüfen eines zweiten Flugzeugsystems (158), wobei die erste Prüfmatrix (133, 225) eine erste Funktionsprüfung (123, 223) beschreibt und die zweite Prüfmatrix (173, 225) eine zweite Funktionsprüfung (163, 223) beschreibt;
während der ersten Funktionsprüfung (123, 223), Abrufen von Sensordaten (151), die erste Sensordaten (175, 253) in einem von der ersten Prüfmatrix (133, 225) spezifizierten Bereich (145, 245) und von der ersten Prüfmatrix (133, 225) nicht spezifizierte zweite Sensordaten (153, 253) aufweisen;
Evaluieren der ersten Funktionsprüfung (123, 223) durch Verarbeiten der ersten Sensordaten (175, 253) unter Verwendung eines ersten analytischen Modells (103, 213) des ersten Flugzeugsystems (156), wobei das erste analytische Modell (103, 213) konfiguriert ist, um erste vorausgesagte Sensordaten (141, 241) auf Basis der ersten Sensordaten (175, 253) zu erzeugen;
Erzeugen der ersten vorausgesagten Sensordaten (141, 241) auf Basis der Evaluation der ersten Funktionsprüfung (123, 223);
Evaluieren der zweiten Funktionsprüfung (163, 223) durch Verarbeiten der zweiten Sensordaten (153, 253) unter Verwendung eines zweiten analytischen Modells (113, 213) des zweiten Flugzeugsystems (158), wobei das zweite analytische Modell (113, 213) konfiguriert ist, um zweite vorausgesagte Sensordaten (181, 241) auf Basis der zweiten Sensordaten (153, 253) zu erzeugen;
Erzeugen der zweiten vorausgesagten Sensordaten (181, 241) auf Basis der Evaluation der zweiten Funktionsprüfung (163, 223);
Erzeugen eines ersten Fehlermaßes (143, 243) durch Vergleichen eines ersten Subsatzes der Sensordaten (147, 257) mit den ersten vorausgesagten Sensordaten (141, 241);
Erzeugen eines zweiten Fehlermaßes (183, 243) durch Vergleichen eines zweiten Subsatzes der Sensordaten (157, 257) mit den zweiten vorausgesagten Sensordaten (181, 241);
Bestimmen einer Prüfabdeckungsmetrik (197, 247) der zweiten Prüfmatrix (173, 225) mindestens teilweise auf Basis eines Bereichs (195, 245) der zweiten Sensordaten (153, 253), wobei die Prüfabdeckungsmetrik (197, 247) angibt, wieviel der zweiten Prüfmatrix (173, 225) abgedeckt worden ist; und
Liefern einer Ausgabe (149, 199, 251) an eine Anzeigevorrichtung (120, 670), wobei die Ausgabe (149, 199, 251) das erste Fehlermaß (143, 243), das zweite Fehlermaß (183, 243) und die Prüfabdeckungsmetrik (197, 247) angibt.

Revendications

1. Procédé (300) de test de systèmes d'aéronef (154) comprenant un premier système d'aéronef (156) et un second système d'aéronef (158), le procédé (300) comprenant :

l'obtention (302), au niveau d'un dispositif (102, 610), d'une première matrice de test (133, 225) permettant de tester le premier système d'aéronef (156) et d'une seconde matrice de test (173, 225) permettant de tester le second système d'aéronef (158), dans lequel la première matrice de test (133, 225) décrit un premier test opérationnel (123, 223), et la seconde matrice de test (173, 225) décrit un second test opérationnel (163, 223) ;
pendant le premier test opérationnel (123, 223), l'obtention (304), au niveau du dispositif (102, 610), de données de capteur (151) qui comprennent des premières données de capteur (175, 253) dans une plage (145, 245) spécifiée par la première matrice de test (133, 225) et des secondes données de capteur (153, 253) qui ne sont pas spécifiées par la première matrice de test (133, 225) ;
l'évaluation (306), au niveau du dispositif (102, 610), du premier test opérationnel (123, 223) en traitant les premières données de capteur (175, 253) au moyen d'un premier modèle analytique (103, 213) du premier système d'aéronef (156), dans lequel le premier modèle analytique (103, 213) est configuré pour générer des premières données de capteur prédites (141, 241) sur la base des premières données de capteur (175, 253) ;
la génération (308), au niveau du dispositif (102, 610), des premières données de capteur prédites (141, 241) sur la base de l'évaluation du premier test opérationnel (123, 223) ;
l'évaluation (310), au niveau du dispositif (102, 610), du second test opérationnel (163, 223) en traitant les secondes données de capteur (153, 253) au moyen d'un second modèle analytique (113, 213) du second système d'aéronef (158),

dans lequel le second modèle analytique (113, 213) est configuré pour générer des secondes données de capteur prédites (181, 241) sur la base des secondes données de capteur (153, 253) ; la génération (312), au niveau du dispositif (102, 610), des secondes données de capteur prédites (181, 241) sur la base de l'évaluation du second test opérationnel (163, 223) ;
la génération (314), au niveau du dispositif (102, 610), d'une première mesure d'erreur (143, 243) en comparant un premier sous-ensemble des données de capteur (147, 257) aux premières données de capteur prédites (141, 241) ;
la génération (316), au niveau du dispositif (102, 610), d'une seconde mesure d'erreur (183, 243) en comparant un second sous-ensemble des données de capteur (157, 257) aux secondes données de capteur prédites (181, 241) ;
la détermination (318), au niveau du dispositif (102, 610), sur la base au moins en partie d'une plage (195, 245) des secondes données de capteur (153, 253), d'une métrique de couverture de test (197, 247) de la seconde matrice de test (173, 225), dans lequel la métrique de couverture de test (197, 247) indique quelle proportion de la seconde matrice de test (173, 225) a été couverte ; et
la fourniture (320), par le dispositif (102, 610), d'une sortie (149, 199, 251) à un dispositif d' affichage (120, 670), la sortie (149, 199, 251) indiquant la première mesure d'erreur (143, 243), la seconde mesure d'erreur (183, 243), et la métrique de couverture de test (197, 247).

2. Procédé (300) selon la revendication 1, dans lequel le premier test opérationnel (123, 223) comprend au moins l'un d'un test au sol, d'un test de roulage, ou d'un test de vol.

3. Procédé (300) selon la revendication 1 ou 2, dans lequel le premier modèle analytique (103, 213) comprend un modèle de physique, un modèle empirique, un modèle statistique, un modèle de simulation, ou une combinaison de ceux-ci.

4. Procédé (300) selon la revendication 1, 2 ou 3, comprenant en outre :

la détermination selon laquelle la seconde matrice de test (173, 225) indique une première plage (261) de données d'un premier capteur (152) ; et
en réponse à la détermination selon laquelle une deuxième plage (245) de données provenant du premier capteur (152) a été traitée au moyen du second modèle analytique (113, 213) pendant une période de collecte de données, la détermination de la métrique de couverture de test (197, 247) sur la base au moins en partie d'une troisième plage (263) de données qui est incluse dans la première plage (261) de données et n'est pas incluse dans la deuxième plage (245) de données, dans lequel la plage (195, 245) des secondes données de capteur (153, 253) inclut la deuxième plage (195, 245) de données provenant du premier capteur (152).

5. Procédé (300) selon l'une quelconque des revendications 1-4, comprenant en outre la détermination, sur la base au moins en partie de la seconde mesure d'erreur (183, 243), d'une métrique de convergence de test (179, 249) de la seconde matrice de test (173, 225), dans lequel la sortie (149, 199, 251) indique la métrique de convergence de test (179, 249).

6. Procédé (300) selon l'une quelconque des revendications 1-5, comprenant en outre :

la réception d'ensembles de données de capteur pendant une période de collecte de données, dans lequel les ensembles de données de capteur comprennent les données de capteur (151) ;
l'évaluation d'une pluralité de seconds tests opérationnels (161) de la seconde matrice de test (173, 225) sur la base du second modèle analytique (113, 213) et des ensembles de données de capteur, dans lequel la pluralité de seconds tests opérationnels (161) comprend le second test opérationnel (163, 223) ;
la détermination d'une pluralité de secondes mesures d'erreur sur la base des évaluations de la pluralité de seconds tests opérationnels (161), dans lequel la pluralité de secondes mesures d'erreur comprend la seconde mesure d'erreur (183, 243) ; et
la détermination d'une métrique de convergence de test (179, 249) de la seconde matrice de test (173, 225) sur la base de la pluralité de secondes mesures d'erreur.

7. Procédé (300) selon la revendication 6, dans lequel la métrique de convergence de test (179, 249) est basée au moins en partie sur un écart-type de la pluralité de secondes mesures d'erreur.

8. Procédé (300) selon l'une quelconque des revendications 1-7, comprenant en outre, en réponse à la détermination selon laquelle la métrique de couverture de test (197, 247) satisfait un critère de couverture et selon laquelle une métrique de convergence de test (179, 249) de la seconde matrice de test (173, 225) satisfait un critère de convergence, générant la sortie (149, 199, 251) pour indiquer que le test du second modèle analytique (113, 213) est terminé.

9. Procédé (300) selon l'une quelconque des revendications 1-8, comprenant en outre, en réponse à la détermination selon laquelle la seconde mesure d'erreur (183, 243) ne satisfait pas un critère d'erreur, la génération de la sortie (149, 199, 251) pour indiquer qu'une erreur est détectée dans le second modèle analytique (113, 213), le second système d'aéronef (158), ou les deux.

10. Aéronef (104, 500) comprenant :

des systèmes d'aéronef (154) comprenant un premier système d'aéronef (156) et un second système d'aéronef (158) ;
une mémoire (132, 630) configurée pour stocker une pluralité de modèles analytiques (111) des systèmes d'aéronef (154), la pluralité de modèles analytiques (111) comprenant un premier modèle analytique (103, 213) du premier système d'aéronef (156) et un second modèle analytique (113, 213) du second système d'aéronef (158), dans lequel le premier modèle analytique (103, 213) est configuré pour générer des premières données de capteur prédites (141, 241) sur la base des premières données de capteur (175, 253), et le second modèle analytique (113, 213) est configuré pour générer des secondes données de capteur prédites (181, 241) sur la base des secondes données de capteur (153, 253) ;
des capteurs (152) configurés pour générer des données de capteur (151) pendant un premier test opérationnel (123, 223) d'une première matrice de test (133, 225) permettant de tester le premier système d'aéronef (156), dans lequel les données de capteur (151) comprennent les premières données de capteur (175, 253) dans une plage (145, 245) spécifiée par la première matrice de test (133, 225) et les secondes données de capteur (153, 253), dans lequel les secondes données de capteur (153, 253) ne sont pas spécifiées par la première matrice de test (133, 225), et dans lequel la première matrice de test (133, 225) décrit le premier test opérationnel (123, 223) ;
un ou plusieurs processeurs (128, 620) configurés pour :

évaluer le premier test opérationnel (123, 223) en traitant les premières données de capteur (175, 253) au moyen du premier modèle analytique (103, 213) ;
générer les premières données de capteur prédites (141, 241) sur la base de l'évaluation du premier test opérationnel (123, 223) ;
évaluer un second test opérationnel (163,223) d'une seconde matrice de test (173, 225) permettant de tester le second système d'aéronef (158) en traitant les secondes données de capteur (153, 253) au moyen du second modèle analytique (113, 213), dans lequel la seconde matrice de test (173, 225) décrit le second test opérationnel (163, 223) ;
générer les secondes données de capteur prédites (181, 241) sur la base de l'évaluation du second test opérationnel (163, 223) ;
générer une première mesure d'erreur (143, 243) en comparant un premier sous-ensemble des données de capteur (147, 257) aux premières données de capteur prédites (141, 241) ;
générer une seconde mesure d'erreur (183, 243) en comparant un second sous-ensemble des données de capteur (157, 257) aux secondes données de capteur prédites (181, 241) ; et
déterminer, sur la base au moins en partie d'une plage (195, 245) des secondes données de capteur (153, 253), une métrique de couverture de test (197, 247) de la seconde matrice de test (173, 225), dans lequel la métrique de couverture de test (197, 247) indique quelle proportion de la seconde matrice de test (173, 225) a été couverte ; et

un dispositif d'affichage (120, 670) configuré pour afficher une sortie (149, 199, 251) indiquant la première mesure d'erreur (143, 243), la seconde mesure d'erreur (183, 243), et la métrique de couverture de test (197, 247).

11. Aéronef (104, 500) selon la revendication 10, dans lequel les capteurs (152) comprennent des capteurs embarqués, des capteurs de test de vol, ou une combinaison de ceux-ci.

12. Aéronef (104, 500) selon la revendication 10 ou 11, dans lequel le second modèle analytique (113, 213) comprend un modèle de physique, un modèle empirique, un modèle statistique, un modèle de simulation, ou une combinaison de ceux-ci.

13. Aéronef (104, 500) selon la revendication 10, 11, ou 12, dans lequel le ou les processeurs (128, 620) sont en outre configurés pour, en réponse à la détermination selon laquelle la métrique de couverture de test (197, 247) satisfait un critère de couverture et une métrique de convergence de test (179, 249) de la seconde matrice de test (173, 225) satisfait un critère de convergence, générer la sortie (149, 199, 251) pour indiquer que le test du second modèle analytique (113, 213) est terminé.

14. Aéronef (104, 500) selon l'une quelconque des revendications 10-13, dans lequel les un ou plusieurs processeurs (128, 620) sont en outre configurés pour, en réponse à la détermination selon laquelle la seconde mesure d'erreur (183,243) ne satisfait pas un critère d'erreur, générer la sortie (149, 199, 251) pour indiquer qu'une erreur est détectée dans le second modèle analytique (113, 213), le second système d'aéronef (158), ou les deux.

15. Dispositif de stockage lisible par ordinateur (132, 630, 640) stockant des instructions (116, 634) qui, lorsqu'elles sont exécutées par un ou plusieurs processeurs (128, 620) d'un dispositif, amènent le ou les processeurs (128, 620) à :

obtenir une première matrice de test (113, 225) permettant de tester un premier système d'aéronef (156) et une seconde matrice de test (173, 225) permettant de tester un second système d'aéronef (158), dans lequel la première matrice de test (133, 225) décrit un premier test opérationnel (123, 223), et la seconde matrice de test (173, 225) décrit un second test opérationnel (163, 223) ;

pendant le premier test opérationnel (123, 223), obtenir des données de capteur (151) qui comprennent des premières données de capteur (175, 253) dans une plage (145, 245) spécifiée par la première matrice de test (133, 225) et des secondes données de capteur (153, 253) qui ne sont pas spécifiées par la première matrice de test (133, 225) ; évaluer le premier test opérationnel (123, 223) en traitant les premières données de capteur (175, 253) au moyen d'un premier modèle analytique (103, 213) du premier système d'aéronef (156), dans lequel le premier modèle analytique (103, 213) est configuré pour générer des premières données de capteur prédites (141, 241) sur la base des premières données de capteur (175, 253) ;

générer les premières données de capteur prédites (141, 241) sur la base de l'évaluation du premier test opérationnel (123, 223) ;

évaluer le second test opérationnel (163, 223) en traitant les secondes données de capteur (153, 253) au moyen d'un second modèle analytique (113, 213) du second système d'aéronef (158), dans lequel le second modèle analytique (113, 213) est configuré pour générer des secondes données de capteur prédites (181, 241) sur la base des secondes données de capteur (153, 253) ;

générer les secondes données de capteur prédites (181, 241) sur la base de l'évaluation du second test opérationnel (163, 223) ;

générer une première mesure d'erreur (143, 243) en comparant un premier sous-ensemble des données de capteur (147, 257) aux premières données de capteur prédites (141, 241) ;

générer une seconde mesure d'erreur (183, 243) en comparant un second sous-ensemble des données de capteur (157, 257) aux secondes données de capteur prédites (181, 241) ;

déterminer, sur la base au moins en partie d'une plage (195, 245) des secondes données de capteur (153, 253), une métrique de couverture de test (197, 247) de la seconde matrice de test (173, 225), dans lequel la métrique de couverture de test (197, 247) indique quelle proportion de la seconde matrice de test (173, 225) a été couverte ; et

fournir une sortie (149, 199, 251) à un dispositif d'affichage (120, 670), la sortie (149, 199, 251) indiquant la première mesure d'erreur (143, 243), la seconde mesure d'erreur (183, 243), et la métrique de couverture de test (197, 247).

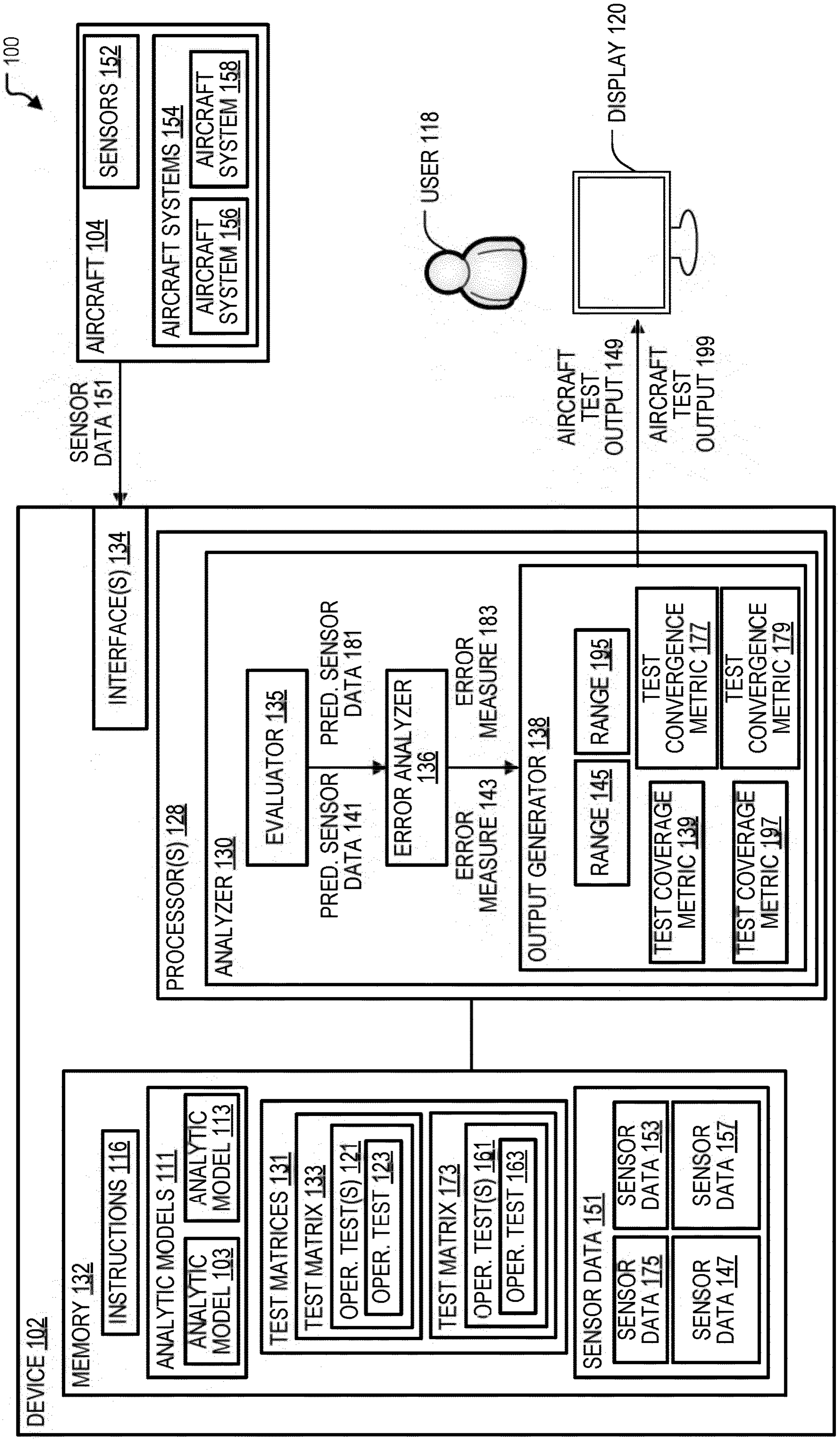
100
AIRCRAFT 104
SENSORS 152
AIRCRAFT SYSTEMS 154
AIRCRAFT SYSTEM 156
AIRCRAFT SYSTEM 158
SENSOR DATA 151
USER 118
DISPLAY 120
AIRCRAFT TEST OUTPUT 149
AIRCRAFT TEST OUTPUT 199
DEVICE 102
INTERFACE(S) 134
PROCESSOR(S) 128
ANALYZER 130
EVALUATOR 135
PRED. SENSOR DATA 141
PRED. SENSOR DATA 181
ERROR ANALYZER 136
ERROR MEASURE 143
ERROR MEASURE 183
OUTPUT GENERATOR 138
RANGE 145
RANGE 195
TEST COVERAGE METRIC 139
TEST CONVERGENCE METRIC 177
TEST COVERAGE METRIC 197
TEST CONVERGENCE METRIC 179
MEMORY 132
INSTRUCTIONS 116
ANALYTIC MODELS 111
ANALYTIC MODEL 103
ANALYTIC MODEL 113
TEST MATRICES 131
TEST MATRIX 133
OPER. TEST(S) 121
OPER. TEST 123
TEST MATRIX 173
OPER. TEST(S) 161
OPER. TEST 163
SENSOR DATA 151
SENSOR DATA 175
SENSOR DATA 153
SENSOR DATA 147
SENSOR DATA 157

FIG. 1

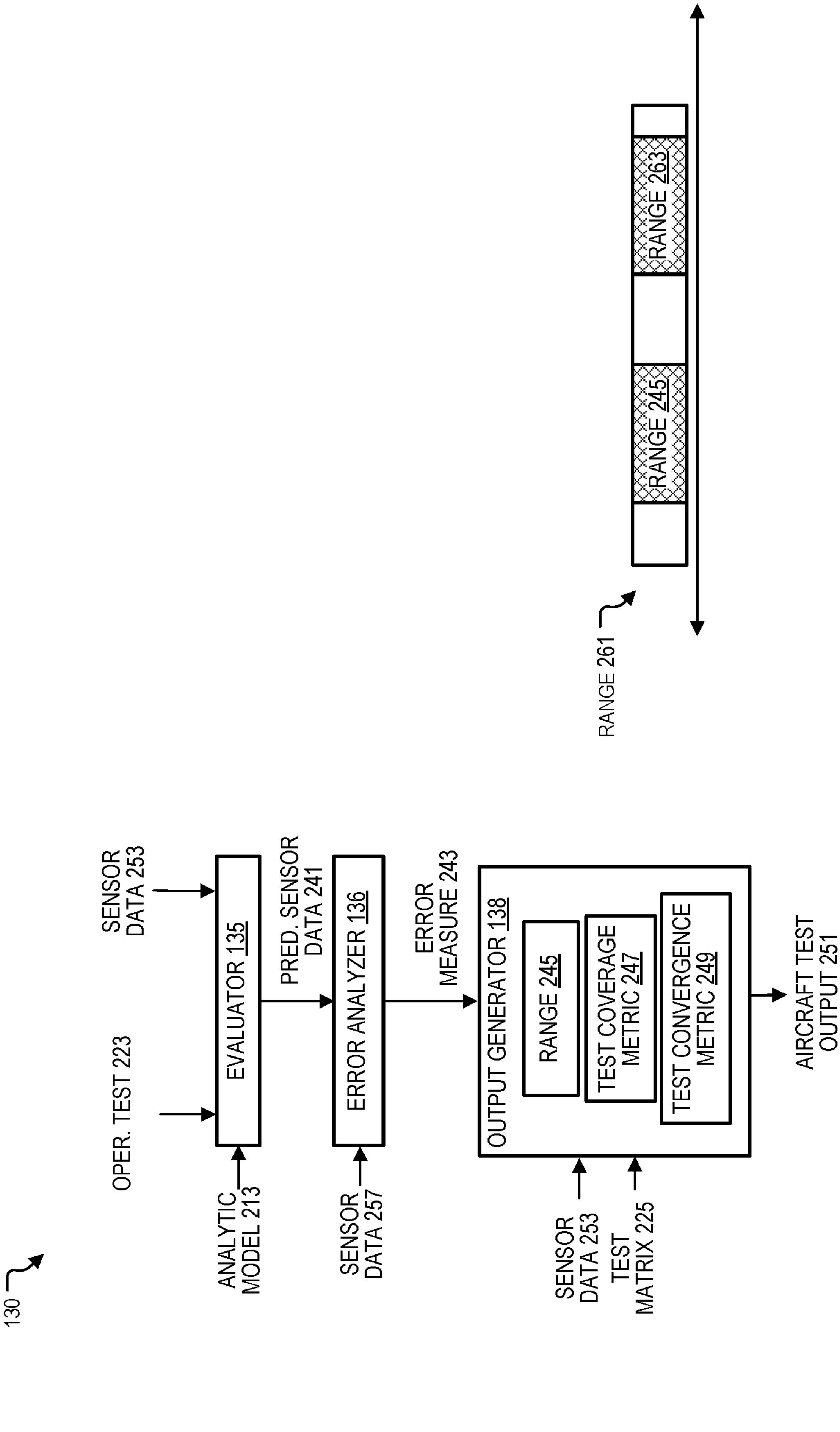
130
OPER. TEST 223
SENSOR DATA 253
ANALYTIC MODEL 213
EVALUATOR 135
PRED. SENSOR DATA 241
SENSOR DATA 257
ERROR ANALYZER 136
ERROR MEASURE 243
OUTPUT GENERATOR 138
RANGE 245
TEST COVERAGE METRIC 247
TEST CONVERGENCE METRIC 249
SENSOR DATA 253
TEST MATRIX 225
AIRCRAFT TEST OUTPUT 251
RANGE 261
RANGE 245
RANGE 263

FIG. 2

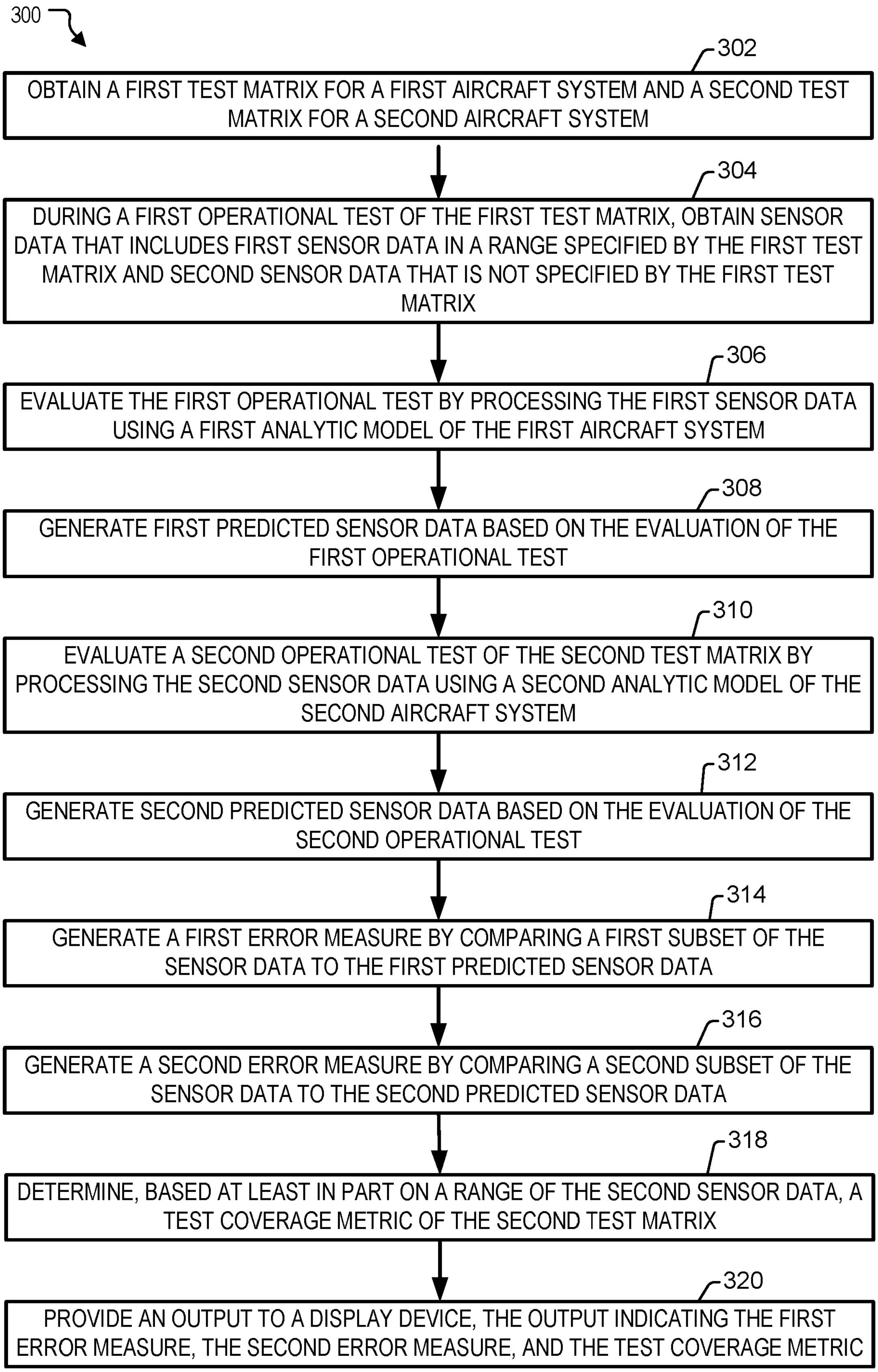
300
302
OBTAIN A FIRST TEST MATRIX FOR A FIRST AIRCRAFT SYSTEM AND A SECOND TEST MATRIX FOR A SECOND AIRCRAFT SYSTEM
304
DURING A FIRST OPERATIONAL TEST OF THE FIRST TEST MATRIX, OBTAIN SENSOR DATA THAT INCLUDES FIRST SENSOR DATA IN A RANGE SPECIFIED BY THE FIRST TEST MATRIX AND SECOND SENSOR DATA THAT IS NOT SPECIFIED BY THE FIRST TEST MATRIX
306
EVALUATE THE FIRST OPERATIONAL TEST BY PROCESSING THE FIRST SENSOR DATA USING A FIRST ANALYTIC MODEL OF THE FIRST AIRCRAFT SYSTEM
308
GENERATE FIRST PREDICTED SENSOR DATA BASED ON THE EVALUATION OF THE FIRST OPERATIONAL TEST
310
EVALUATE A SECOND OPERATIONAL TEST OF THE SECOND TEST MATRIX BY PROCESSING THE SECOND SENSOR DATA USING A SECOND ANALYTIC MODEL OF THE SECOND AIRCRAFT SYSTEM
312
GENERATE SECOND PREDICTED SENSOR DATA BASED ON THE EVALUATION OF THE SECOND OPERATIONAL TEST
314
GENERATE A FIRST ERROR MEASURE BY COMPARING A FIRST SUBSET OF THE SENSOR DATA TO THE FIRST PREDICTED SENSOR DATA
316
GENERATE A SECOND ERROR MEASURE BY COMPARING A SECOND SUBSET OF THE SENSOR DATA TO THE SECOND PREDICTED SENSOR DATA
318
DETERMINE, BASED AT LEAST IN PART ON A RANGE OF THE SECOND SENSOR DATA, A TEST COVERAGE METRIC OF THE SECOND TEST MATRIX
320
PROVIDE AN OUTPUT TO A DISPLAY DEVICE, THE OUTPUT INDICATING THE FIRST ERROR MEASURE, THE SECOND ERROR MEASURE, AND THE TEST COVERAGE METRIC

FIG. 3

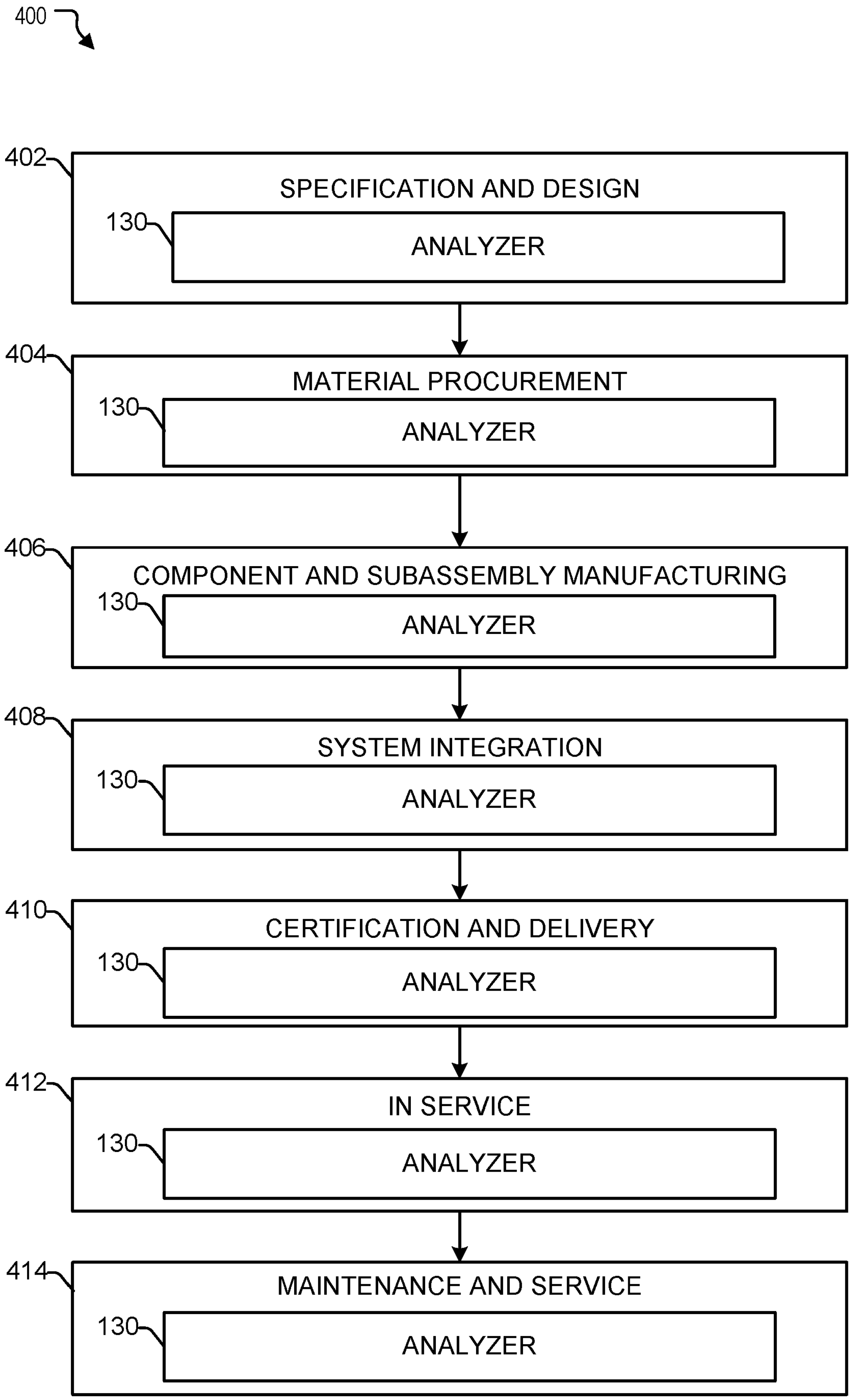
400
402
SPECIFICATION AND DESIGN
130
ANALYZER
404
MATERIAL PROCUREMENT
130
ANALYZER
406
COMPONENT AND SUBASSEMBLY MANUFACTURING
130
ANALYZER
408
SYSTEM INTEGRATION
130
ANALYZER
410
CERTIFICATION AND DELIVERY
130
ANALYZER
412
IN SERVICE
130
ANALYZER
414
MAINTENANCE AND SERVICE
130
ANALYZER

FIG. 4

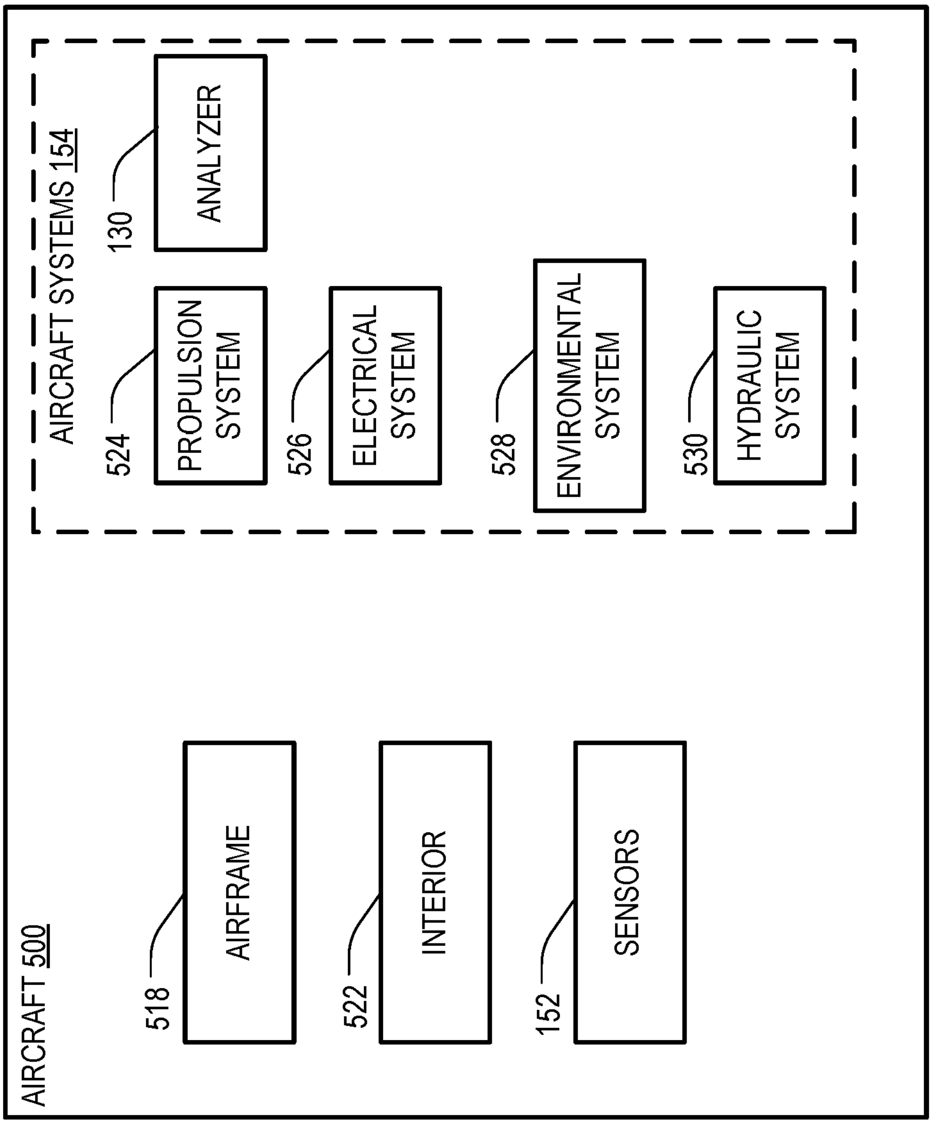
AIRCRAFT 500
518
AIRFRAME
522
INTERIOR
152
SENSORS
AIRCRAFT SYSTEMS 154
524
PROPULSION SYSTEM
526
ELECTRICAL SYSTEM
528
ENVIRONMENTAL SYSTEM
530
HYDRAULIC SYSTEM
130
ANALYZER

FIG. 5

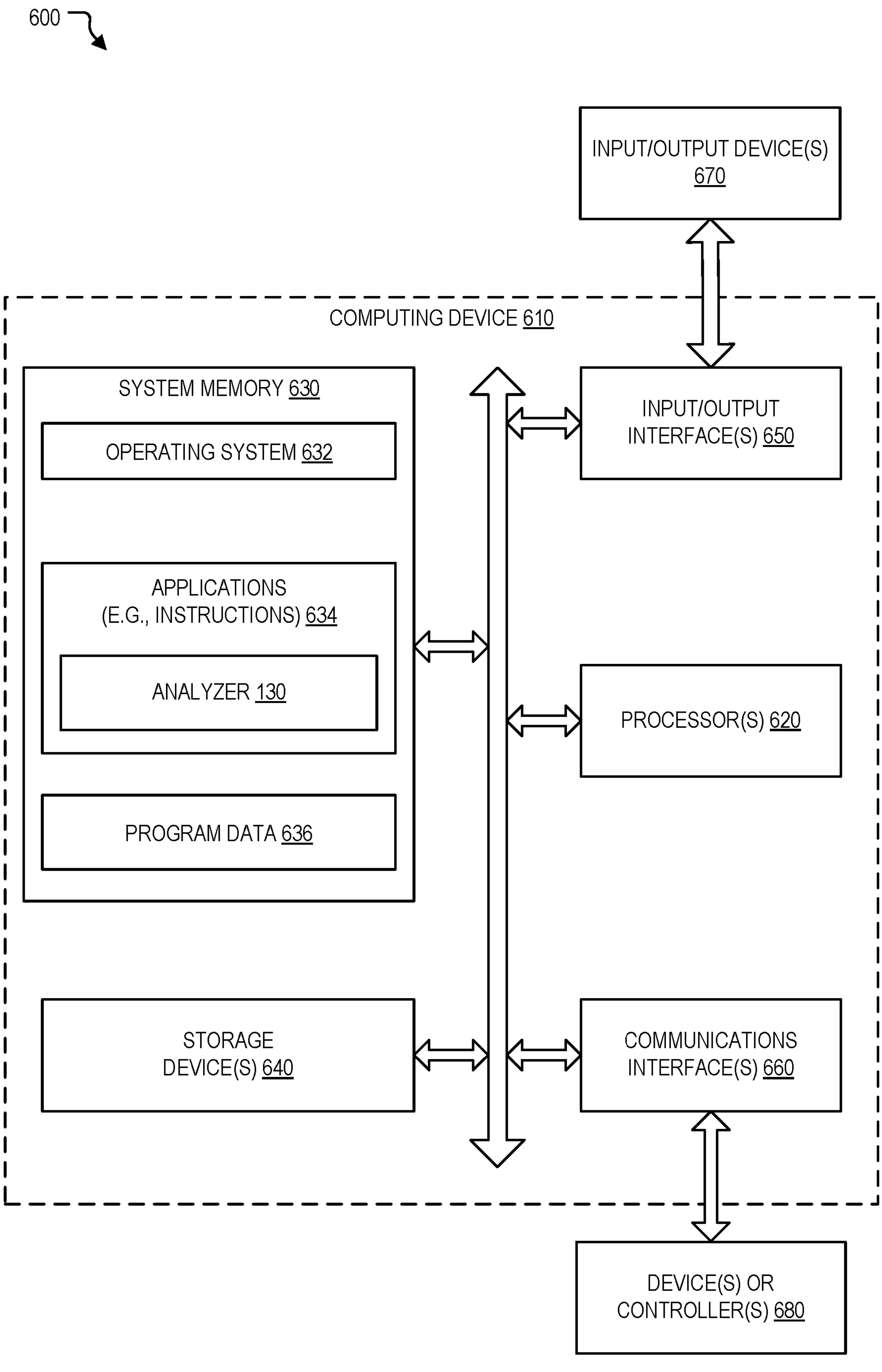
600
INPUT/OUTPUT DEVICE(S) 670
COMPUTING DEVICE 610
SYSTEM MEMORY 630
OPERATING SYSTEM 632
APPLICATIONS (E.G., INSTRUCTIONS) 634
ANALYZER 130
PROGRAM DATA 636
INPUT/OUTPUT INTERFACE(S) 650
PROCESSOR(S) 620
STORAGE DEVICE(S) 640
COMMUNICATIONS INTERFACE(S) 660
DEVICE(S) OR CONTROLLER(S) 680

FIG. 6

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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